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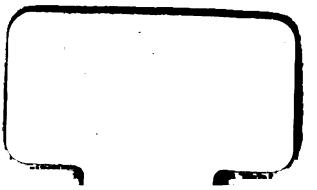

SEARCHLIGHTS

SEARCHLIGHTS:

THEIR THEORY, CONSTRUCTION AND APPLICATIONS

BY

F. NERZ

TRANSLATED

BY

CHARLES RODGERS

NEW YORK

D. VAN NOSTRAND COMPANY

23 MURRAY AND 27 WARREN STREETS

1907

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AUTHOR'S PREFACE TO THE ENGLISH EDITION.

On being asked to write a general treatise on Searchlights for Professor Voit's *Sammlung elektrotechnischer Vorträge*, the author felt unable to decline, as he had had in mind for a considerable time the preparation of a small work embodying the results which he had collected and the experience gained by him during an acquaintance with this class of apparatus extending over many years. To this was added the fact that searchlights were being employed for an increasingly large number of purposes, and that the circle of those interested in their use was rapidly widening. There was, however, no comprehensive work in existence which might serve as an introduction to the subject.

The present book was designed to meet this want. It was intended to give details of construction and of working, which would be useful to officers and engineers who had to handle searchlights, and on the other hand, to furnish the essential technical data required by the designer.

In order to meet these requirements, the history and general theory of searchlights are first treated

of, special attention being given to parabolic mirrors. Then follows a description of some typical searchlights with their accessories, a chapter on details of construction, and finally, an account of various systems of transportable power supply.

The present translation is in effect a new edition, as numerous alterations have been made in the illustrations and the text so as to bring the book into line with present practice.

F. NERZ.

NÜRNBERG,
September, 1907.

TRANSLATOR'S NOTE.

THE present translation was undertaken at the request of several officers, who felt the need of a book such as this. The author has kindly supplied much valuable new material, and has practically rewritten the later sections. It is hoped that the book will be of assistance to those who are interested in searchlights

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SEARCHLIGHTS.

CHAPTER I.

INTRODUCTION.

It is found in practice that the light of the full moon is sufficient to enable a torpedo boat at a distance of about 1,000 metres to be seen with sufficient distinctness to enable an attack to be repelled. We will now examine whether it is possible to obtain such an illumination from an artificial source.

The illumination produced by the full moon at the earth's surface is about 0·16 lux. In order to produce this illumination at a distance of 1,000 metres, the intensity of the source of light must be 160,000 candle power. The most powerful source of light at present available is an electric arc taking about 150 amperes, and the curve of light distribution of such an arc is shown on Fig. 1. It will be seen that the line of greatest intensity makes an angle of about 45° with the axis of the carbons.

In order to use these rays for the illumination of an object 1,000 metres distant, the arc would have

to be raised to a height of 1,000 metres. If we were limited to a height of 20 metres we should only obtain a candle power of 10,000, which would give at 1,000 metres distance an illumination of only 0·010 lux. An arc alone is, therefore, unsuitable for the purpose; the illumination in the immediate neighbourhood, which should be as small

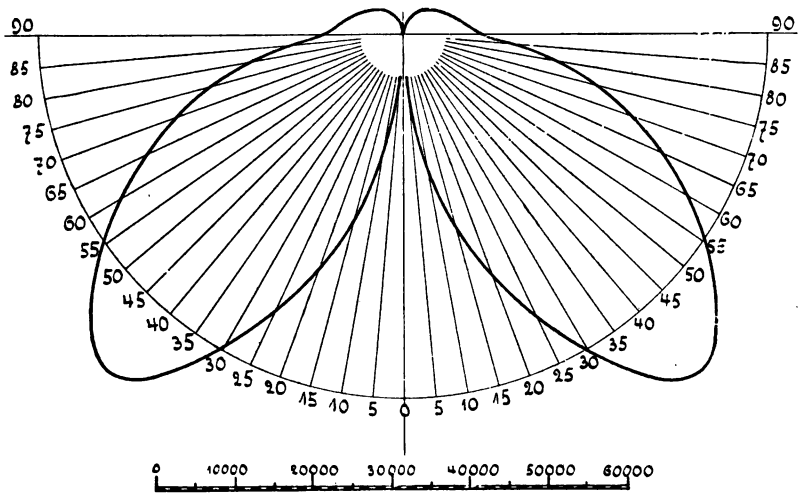


FIG. 1.

as possible, is much too strong, and at great distances where it is specially required is quite insufficient. If a means could be found for utilising the rays wasted in the immediate neighbourhood a great improvement would be effected. For instance, if the rays in the zone of greatest intensity were reflected from a conical mirror as shown in Fig. 2, a better result would be obtained. If the mirror were one metre from the arc, and the

object to be illuminated 1,000 metres away, the illumination at the object would be 10^{-6} times that at the mirror, on account of the distance, and would be further reduced as the sine of the angle of emission. The illumination, therefore, which could be obtained at 1,000 metres distant by means of a conical mirror would be about $58{,}000 \times 10^{-6} \sin 45° = \cdot 04$ lux. Such a conical mirror can reflect only a small portion of the total

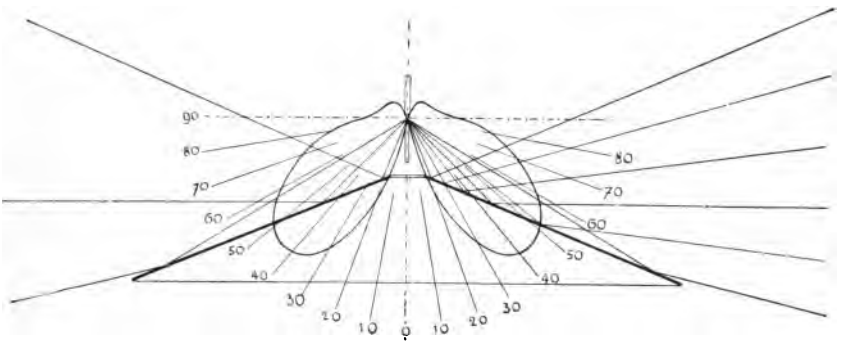


FIG. 2.

light emitted by the arc, and of this light reflected only a small part is useful, all rays reflected above the horizon being lost.

Instead of a conical mirror, one of the form shown in Fig. 3 may be used, consisting of a hyperbola with its axis horizontal and focus in the arc, rotated about the vertical M N passing through the carbons. Rays emitted from the arc with an angle between them will, after reflection, have an angle β between them as if they were emitted from the other focus f_1 of the hyperbola. By

suitably choosing the hyperbola it is therefore possible to modify the angle of emission so as to obtain a better illumination than in Fig. 2, since the intensity of the reflected rays is proportional to the angle of emission.

A still greater increase in intensity can be obtained by using a parabola instead of a hyperbola. But it will be found with either

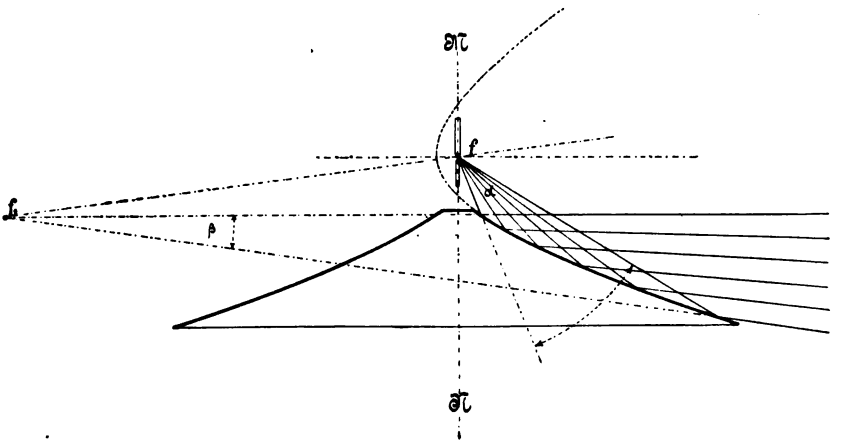


FIG. 3.

parabolic or hyperbolic mirrors of this class that in order to utilise as much light from the arc as possible mirrors of such large size would be required that their manufacture would be an impossibility.

To obtain the best possible result, other means must be found. If, for instance, beneath a vertical arc a parabolic or hyperbolic mirror is placed with its axis vertical and its focus

in the arc, a cone of light will be reflected upwards having a definite angle. If now in this vertically directed cone of light a conical mirror is placed with its axis vertical, the light will be reflected outwards, and by suitably arranging the conical angle can be made to illuminate a circle of 1,000 metres radius.

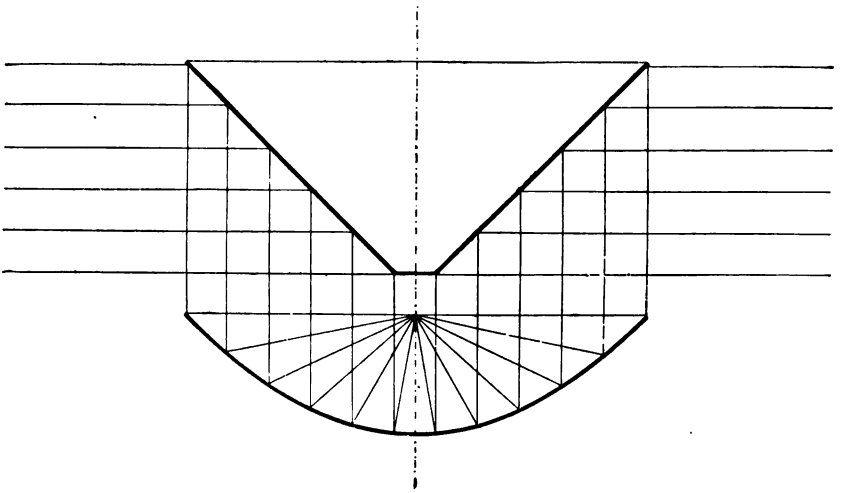


FIG. 4.

By the use of such parabolic and hyperbolic mirrors it would be possible to utilise the greater part of the light coming from the arc for the desired purpose, and the cone of light utilised could be of any angle up to 180°. This solid angle, subtended at the arc by the edge of the mirror, we shall call the *effective angle* of the mirror.

In order to determine what gain is to be expected by increasing the effective angle of the mirror we must first examine closely the distribution of light in the neighbourhood of the arc. If the curve of light intensity in various directions in a plane passing through the axis of the carbons is plotted, the curve shown in Fig. 1 is obtained. The illumination of equal surfaces at the same distance from the source of light is proportional to the quantity of light falling on each surface respectively, whatever the system of mirrors used.

For a given effective angle the total quantity of light emitted can be found by splitting up the surface of the mirrors into zones, multiplying the area of each zone by the mean intensity of the light falling on it and summing this product for all zones.

If this is done for the arrangement last described, it will be found that the intensity of illumination at a distance of 1,000 metres can be increased to six times the value obtainable without any mirrors. An intensity of 0·24 lux could therefore be obtained, which is already greater than that of the full moon. The actual intensity obtainable would, however, be much less than this calculated value, as in making the calculation the absorption of the atmosphere has been neglected. Moreover, even if the same illumination could be obtained at 1,000 metres as with full moon, distant objects would not be so well seen as on a moonlight night; for the full moon

gives a uniform illumination of 0·16 lux, whereas the above arrangement of mirrors would illuminate near objects much more strongly, causing the eye to receive more stray light than in the case of the full moon. The image of the distant object, formed in the eye, is therefore indistinct, and the illumination would have to be considerably increased to obtain a satisfactory result. It is evident that the arrangements so far described, are unsuitable for this purpose. Also the Fresnel's lenses, so much used in lighthouses, and which enable almost the whole of the light emitted by the arc to be utilised, would not give a sufficiently great increase in the illumination.

In very many cases it would be sufficient to illuminate only a small part of the horizon. If, therefore, all the light emitted could be concentrated into a small angle a corresponding increase in intensity would be obtained and the problem would be nearer solution. For instance, if in Fig. 4 the conical mirror is removed, a beam of light reflected vertically upwards is obtained. If the lamp and parabolic mirror are turned about a horizontal axis until the beam of light illuminates the desired point, an illuminated area corresponding to the angle of the cone of light coming from the mirror will be obtained. If this is, say 3°, the intensity of illumination will be greater than that obtained with the arrangement of Fig. 4 in the ratio 360/3, that is, 120 fold. This is the

arrangement which is now in general use for searchlights.

Before going further into this subject, we shall first give a historical description of the development of the design of searchlights.

CHAPTER II.

HISTORICAL.

It is now many years since the first attempt was made to use parabolic mirrors in lighthouses. The mirrors were made of metal, which came in its various forms to be known as speculum metal. It was found difficult to prepare parabolic mirrors from this metal and to keep them for any length of time in good condition: they had only a small reflecting power and soon lost their polish. According to the observations of various experimenters the loss of light on reflection varied according to the condition of the surface between 30 and 45 per cent.

Glass, however, is an excellent material for this purpose, as it is capable of taking a high polish, and when silvered possesses excellent reflecting properties; for a long time, however, all efforts to manufacture parabolic mirrors of sufficient accuracy from glass were unsuccessful. The mirrors had therefore to be made with a spherical surface. This, however, necessitated the use of small effective angles; for as soon as the ratio of mirror diameter to focal length exceeded a certain value, the deviation of the reflected light from parallelism became so great that no advantage

could be gained by increasing the effective angle.

When the optical systems devised by Fresnel were found capable of giving good results in light-houses, the attempt was made to use them with searchlights. A convex glass lens will transmit rays which come from its focus in a nearly parallel beam along the axis so long as the diameter of the lens is small compared to its focal length. But only a small part of the light coming from the source can be utilised by such a lens. If the ratio of diameter to focal length is increased so that the effective angle becomes greater, the deviation from parallelism in the transmitted beam, that is the spherical aberration, becomes considerable owing to the spherical form of the lens surfaces, exactly as in the case of the spherical mirror. In addition to this, owing to increase in the thickness of the glass, the absorption and loss of light in the lens and the breaking up of the white light into colours is considerably increased.

In order to obviate these defects, Fresnel constructed lenses out of concentric rings (Fig. 5) and surrounded the lens with a system of concentric totally reflecting prisms which transmitted that part of the light falling outside the lens, in the direction of the lens axis. By this means he succeeded in reducing the spherical aberration by suitably choosing the radii of curvature of the lens and in decreasing the amount of absorption through being able to use thinner glass. But Fresnel's

optical systems were unable to hold the field in the case of searchlights in face of later inventions, although those systems are still unexcelled for lighthouses. It was difficult to manufacture the prisms with such exactness that all their foci coincided, and in addition they possessed spherical aberration and chromatic effects. Also in case the source of light moved, the rays transmitted from the prisms altered their direction in the opposite sense to those from the lens. For example, in Fig. 5, if the source moves from the common focus f outwards to a point f_1 the rays passing through the lens come to a focus nearer the lens, but those passing through the prisms come to a focus at various points further away. The beam is, therefore, broken up, causing an increase in the area illuminated, with consequent decrease in the intensity of illumination.

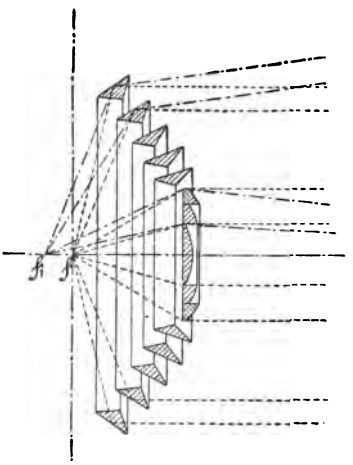


FIG. 5.

A great advance was made in the design of searchlights when it was shown by Mangin that spherical aberration on reflexion from a spherical mirror could be almost entirely avoided by giving the glass the form of a concavo-convex lens instead of making it of uniform thickness as had previously

been done. A ray of light falling on the mirror and reflected from the silvered convex side is then refracted from the glass into the air in such a way that the deviation from parallelism with the axis on account of the spherical form of the silvered surface is very small indeed. Mangin determined the best ratio for the radii of front and back surfaces, and found that the spherical aberration could be made practically negligible when the diameter of the mirror was not greater than its focal length. A mirror constructed on this principle in 1876 by Sautter, Lemonier & Co. was found to possess in a greater degree than any other optical device till then tried, the property of reflecting in a parallel beam rays coming from a source situated at the focus. On the other hand, the effective angle was only about 60° on account of the comparatively great focal length, and the mirror therefore reflected only a small part of the light emitted by the source.

The manufacturers afterwards reduced the focal length of the mirror and contented themselves with an approximation to the law laid down by Mangin.

Attempts have been made to build up parabolic mirrors from a number of separate rings ground to a suitable curvature, but the manufacture of these so-called meniscus rings is attended with much difficulty. They have, as with the Fresnel lenses, the defect that the foci of the separate parts is not easily arranged to be at exactly the same point, and further that at the joints a considerable part of the surface of the mirror becomes useless even when

the neighbouring surfaces are ground exactly to fit one another. After Schuckert in Nuremberg had succeeded, in the year 1886, in manufacturing parabolic mirrors from one piece of glass according to the method patented by him and Munker, it was found that this was undoubtedly the best mirror for searchlights.

CHAPTER III.

PARABOLIC MIRRORS.

If a point source of light is placed at the focus of a true parabolic mirror all the rays falling on the mirror will, as shown in Fig. 6, be reflected parallel to the axis.

Let B A H be a parabola and O its focus. Describe about O an arc of a circle cutting the axis in D and the parabola in B and H. The points B and H will be equidistant from the axis, and the line B G H joining them will cut the axis perpendicularly at a point G. If now B D H and B A H are rotated about the common axis A O, a spherical and a parabolic surface will be obtained, both having the same effective angle B O H $= \phi$. If further a point source of light of intensity J is placed at the focus O, the total quantity of light falling on the spherical surface will be proportional to J and to area of the surface. The area of the surface is $2\pi\rho \times \rho\,(1-\cos \phi/2)$ and the total quantity of light falling on it is therefore

$$Q = \frac{J 2\pi\rho^2}{\rho^2}\left(1-\cos\frac{\phi}{2}\right)$$

and since $1-\cos\frac{\phi}{2} = 2\sin^2\frac{\phi}{4}$

we have $$Q = J\ 4\pi \sin^2\frac{\phi}{4}.$$

$4\pi \sin^2 \frac{\phi}{4}$ is a measure of the solid angle subtended at the source by the mirror.

The paraboloid B A H receives the same quantity of light, and if the source of light were a point source, that is, one having an infinitely small area,

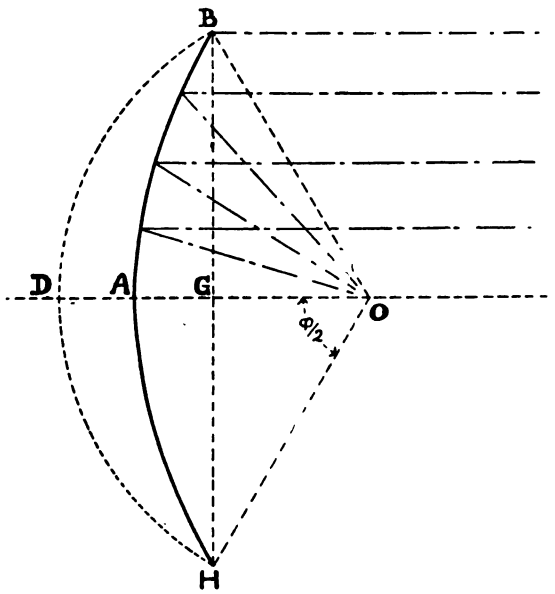


FIG. 6.

the light would be reflected parallel to the axis as a perfectly cylindrical beam, and at any given distance away a circular area would be illuminated having the same diameter as that of the mirror. If the focal length of the mirror were smaller the same quantity of light could be collected by a mirror of smaller diameter, the diameter of the cylindrical

beam would be smaller and its intensity would be increased.

Mangin mirrors always produce some deviation from parallel reflection in consequence of their spherical form, even if these be manufactured with mathematical exactness; they produce therefore, instead of a cylindrical, a conical beam which causes a diminution in intensity at increasing distances from the mirror, proportional to the increase in section of the cone of light. With a parabolic mirror, on the contrary, we have a truly cylindrical beam having the same intensity at all distances from the mirror.

It is found in practice that even from a parabolic mirror the beam of light obtained is not truly cylindrical but of distinctly conical form. Even a mathematically exact parabolic mirror cannot in practice produce a truly cylindrical beam of light, since a source of light of infinitely small area does not exist. It would, in fact, be useless for the purpose, for even if it were possible to see objects at a distance of 1,000 metres which were illuminated over a disc of the same diameter as that of the mirror in use, say 90 cms., it would be impossible to examine the whole of the horizon in less than 1 hour 65 minutes, supposing that the illuminated surface could be sufficiently examined in one second.

If we consider a source of light having the form of a circular disc of diameter $d = ac$ (Fig. 7), and if the focal length of the mirror is f, rays coming

from the centre F will be reflected parallel to the axis, and those coming from other parts of the source will be reflected with a certain deviation from parallelism, which is greater the greater the distance from the centre of the disc. Thus a ray coming from the point *a* to the vertex will be reflected to *c*, and the angle which the lines joining *a* and *c* with the

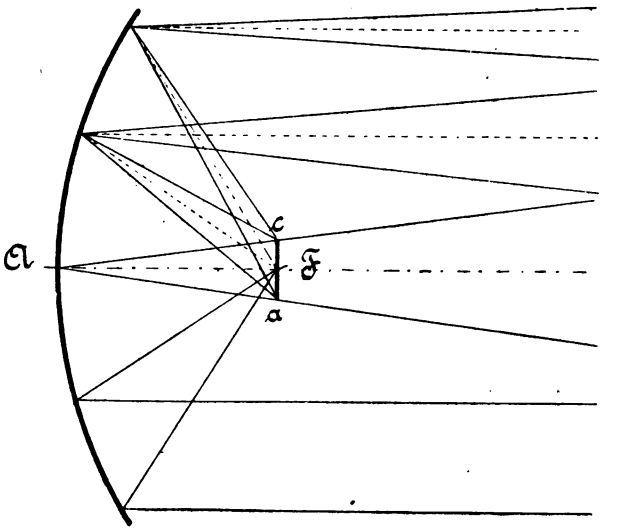


FIG. 7.

centre of the mirror include gives the conical angle of the reflected beam. This is determined by the size and distance of the source of light, and gives a measure of the theoretical dispersion of the beam obtained with the mirror and source of light used. Just as in the case of the vertex so for every other point of the mirror, rays are received from the source and reflected in a cone having a certain vertical

angle which diminishes as the edge of the mirror is approached, so that from every point of the mirror there is reflected a cone of light whose axis is parallel to the axis of the mirror. Since all the axes of these light cones fall within a cylinder whose diameter is equal to the diameter of the mirror, and since the sections of the cones have different values at a given distance, it follows that the illumination produced by a searchlight with a parabolic mirror is most intense in the centre and falls off towards the edge.

The greatest angle of divergence at which the rays of light are reflected from the mirror we shall call the *angle of the reflected beam.* From what has been said above this has the value α where $\tan\frac{\alpha}{2}=\frac{d}{2f}$, and at a great distance e from the mirror, a surface will be illuminated having a diameter $F=\frac{ed}{f}$. This surface will be illuminated (supposing perfect reflection from the mirror) by the original quantity of light,

$$J 4\pi \sin^2\frac{\phi}{4}.$$

If the beam of light were exactly parallel the quantity of light at this distance would be distributed over an area equal to $\frac{\pi D^2}{4}$, where D is the diameter of the parabolic mirror, but as the light is distributed over a larger area the intensity of illumination will be less in the ratio of $\frac{D^2}{F^2}$. If no mirrors were used

and the surface F were illuminated by the same source of light emitting rays equally in every direction, the quantity of light falling on this surface would be

$$Q = J 4\pi \sin^2 \frac{\alpha}{4}.$$

$$\text{The ratio } \frac{\text{Quantity with mirror}}{\text{Quantity without mirror}} = \frac{J 4\pi \sin^2 \frac{\phi}{4}}{J 4\pi \sin^2 \frac{\alpha}{4}}$$

$$= \frac{\sin^2 \frac{\phi}{4}}{\sin^2 \frac{\alpha}{4}}$$

gives a measure of the increased effect, that is, the *intensification* of the mirror. In practice the relation is slightly different, since only that part of light falling on the vertex of the mirror is reflected at an angle α, while for every other part of the surface the dispersion is smaller.

In practice we can with sufficient accuracy write $\frac{D^2}{d^2}$ for $\frac{\sin^2 \frac{\phi}{4}}{\sin^2 \frac{\alpha}{4}}$ (when d is the diameter of the source of light), so that the intensification of the mirror may be written in the simpler form D^2/d^2.

Sources of light such as have been assumed above do not exist in practice. The only source of light which is at present at all suitable is the electric arc, since it has an extremely high intensity and is of very small dimensions, but the assumption

with regard to disc shape does not hold exactly in the case of the arc.

The most important part of the arc is the glowing crater of the positive carbon, and this, therefore, should be placed at the focus of the mirror. The negative carbon emits a comparatively small quantity of light, and the arc itself a very small amount. The negative carbon, owing to its position, throws a shadow on to the mirror, and various means have been tried to diminish the loss of light produced by this shadow. The best known method is that where carbons are used at an angle of 20° to 30° with the vertical, and where the negative carbon, which is usually the lower one, is situated nearer to the object to be illuminated. By this means a greater intensity is obtained in one direction, but the arrangement has shown itself suitable only with mirrors of small effective angle. As soon as the effective angle reaches a certain value the lamp with carbons arranged in the axis of the mirror is found to be the best, so that in this case the carbons are approximately horizontal. The advantage of this arrangement is doubtless due to the fact that part of the light coming from the negative carbon is reflected from the crater of the positive carbon and thereby increases the total quantity of light emitted from the latter.

Schuckert at once recognised the advantages of the horizontal carbons, and used this arrangement from the very beginning with his parabolic mirrors.

Sautter, Lemonier & Co., afterwards Sautter, Harlé & Co., of Paris, the manufacturers of the Mangin mirror, considered the vertical lamp to be most suitable for their searchlights, and defended its use even after it had been shown by tests that the horizontal lamp possesses advantages even for mirrors with an effective angle of 83°. In 1894, however, after the effective angle of the Mangin mirror had been increased, the horizontal lamp was adopted by Sautter, Harlé & Co. also. The horizontal lamp is, therefore, most generally used at the present time.

The formula we have developed for a source of light having uniform intensity in all directions can only be applied to searchlights with horizontal lamps, after considerable modification. The curve in Fig. 1 gives the distribution of light intensity for an electric arc. If we consider that part of the light falling on the parabolic mirror and multiply the mean intensity J_m by the solid angle subtended by the mirror, which we have seen above is equal to $4\pi \sin^2 \frac{\phi}{4}$, a measure is obtained of the amount of light reflected when all losses are neglected, namely:—

$$Q = J_m 4\pi \sin^2 \frac{\phi}{4}.$$

If the light coming from the mirror were uniformly distributed throughout a cone of vertical angle α, a surface of diameter F and area $4\pi e^2 \sin^2 \frac{\phi}{4}$ would

be obtained at a distance e, and the illumination of this surface would be :

$$E = \frac{J_m 4\pi \sin^2 \frac{\phi}{4}}{e^2 4\pi \sin^2 \frac{a}{4}} = \frac{J_m \sin^2 \frac{\phi}{4}}{e^2 \sin^2 \frac{a}{4}}.$$

Since the quantity of light falling on the surface is the same as that falling on the mirror, the intensity at the surface would be :—

$$J_e = J_m \frac{D^2}{F^2}.$$

This formula is only correct in so far as the assumption that the illumination is uniform is correct.

But, as we have seen above, the beam of light reflected from the mirror is not uniform, the brightness being greatest towards the centre and falling off rapidly at the edge.

As the beam of light sends a considerable quantity of light into the eye of the observer through its illuminating objects in the neighbourhood, and on account of mist and dust floating in the atmosphere, the object to be illuminated will be veiled according as a larger or smaller portion of the beam has to be looked through. The object should therefore be illuminated with that edge of the cone of light which is nearest to the observer. As a rule there are several observers present who are not always situated on the same side of the beam, and in that case the object must be illuminated with the central portion of the beam; but then, in

order to see as well with the centre of the beam as with the edge, the illumination in the centre must be greater than at the edge. The greatest difference in brightness between the centre and the edge will be brought out when the mirror is truly parabolic. The manufacturer has the power of introducing definite alterations in the form of the mirror which tend to make the illumination uniform, but an increase of the central illumination up to 35 per cent. above the mean intensity of the beam has shown itself to be advantageous, and has been used in practice.

The determining factors for the distribution of intensity, and for the intensity of the beam of light as a whole, is the intensification, that is, the correct choice of the effective angle and the angle of the beam. As upper limits 140° may be taken for the effective angle, and 3° for the angle of dispersion.

Special conditions will, however, often be specified. In many cases this is done without serious reason, and often only in order to follow previous custom. It is often required, for instance, to increase the total quantity of light with the intention of increasing the penetration of the search-light. The formula already given for the intensity of illumination of distant objects is

$$E = \frac{J_m \sin^2 \frac{\phi}{4}}{e^2 \sin^2 \frac{\alpha}{4}}.$$

Now the mean intensity J_m and also $\sin^2 \frac{\alpha}{4}$ are both proportional to the area of the crater. But the area of the crater increases in proportion to the electrical energy without great increase in intrinsic

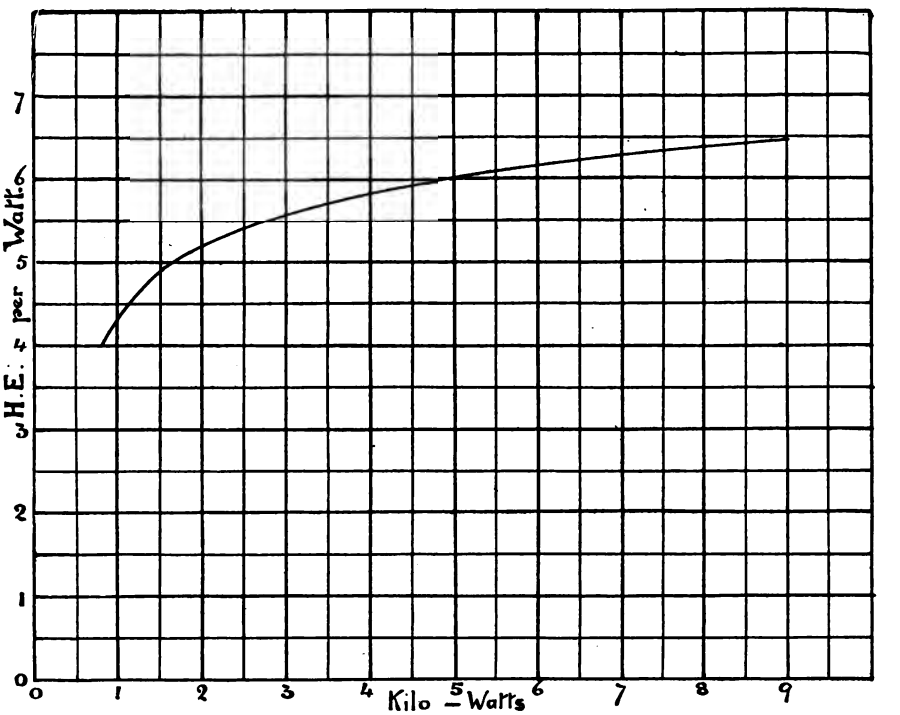


FIG. 8.

brilliancy, so that the ratio $\frac{J_m}{\sin^2 \frac{\alpha}{4}}$ remains about the same with increasing current strength. With a larger quantity of light there is, therefore, no appreciable gain in penetrating power. If the

intensity in the zone of greatest illumination is divided by the power used in watts and the result is plotted, as shown in Fig. 9, against the watts, it will be seen that for small lamps using a small number of watts a considerable increase in intrinsic brilliancy of the crater takes place with increasing current strengths, and that the area of the crater does not increase in the same proportion as the total quantity of light. But at higher currents the increase in intrinsic brilliancy is very small. Also with increasing current strength the irregularity in the form of the crater increases, and the carbons themselves are not so good in the larger sizes, so that practically there is no increase in penetrating power obtainable by increasing the current beyond a certain value.

CHAPTER IV.

PERFORMANCE OF SEARCHLIGHTS.

THE light from a searchlight can penetrate to more than 100 kilometres, so that the effect of the beam can be distinctly perceived, but the illumination is then not sufficient to render objects visible to an observer in the neighbourhood of the searchlight. Such an illumination can only be produced for distances up to a few kilometres. In order to understand the reason for this we must examine more closely the conditions under which illuminated objects can be seen.

The most important factors are :—

(1) The total quantity of light received.

(2) The nature of the surface illuminated, particularly as to its colour and reflecting properties.

(3) The transparency of the atmosphere.

(4) The nature of the objects surrounding that considered.

The effect is also dependent on the position and handling of the searchlight.

In what follows we shall treat of these general considerations more closely.

The intensity of a searchlight is defined as the ratio of the total quantity of light reflected from the mirror to the solid angle of the cone of light.

The total quantity of light reflected (assuming no loss on reflection) is

$$Q = \frac{\pi}{4} i d^2,$$

where i is the intrinsic brilliancy of the source. The solid angle subtended by the source at the centre of the mirror is $4\pi \sin^2 \alpha/4$.

Therefore the intensity $K = \dfrac{i d^2}{16 \sin^2 \frac{\alpha}{4}}$.

Since α is a small angle we can put

$$\sin\frac{\alpha}{4} = \tfrac{1}{2} \sin\frac{\alpha}{2} = \tfrac{1}{2} \tan\frac{\alpha}{2} = \tfrac{1}{2} \left(\frac{d}{2f}\right),$$

so that

$$\sin^2\frac{\alpha}{4} = \tfrac{1}{16} \left(\frac{d}{f}\right)^2,$$

and therefore

$$K = i f^2$$

where f is the focal length of the mirror. But for different sizes of mirrors the ratio of diameter to focal length is approximately constant, so that we can write

$$K = C i D^2$$

where C is a constant.

The intensity of a searchlight is therefore directly proportional to the area of the mirror (or to the square of its diameter), and to the intrinsic brilliancy of the source of light. The latter is defined as the ratio of the total quantity of light emitted to the area of the source, which in this case is approximately equal to the area of the crater of the positive carbon.

In Fig. 9, S is a searchlight, F the object

illuminated, and O the position of the observer. The distance between S and F we shall call the distance of illumination designated by *a*, and the distance between F and O the observing distance designated by *b*.

In testing searchlights the distances to be dealt with are very large in comparison with the diameter of the mirror, so that the cone of light coming from the mirror can be considered as coming from a point.

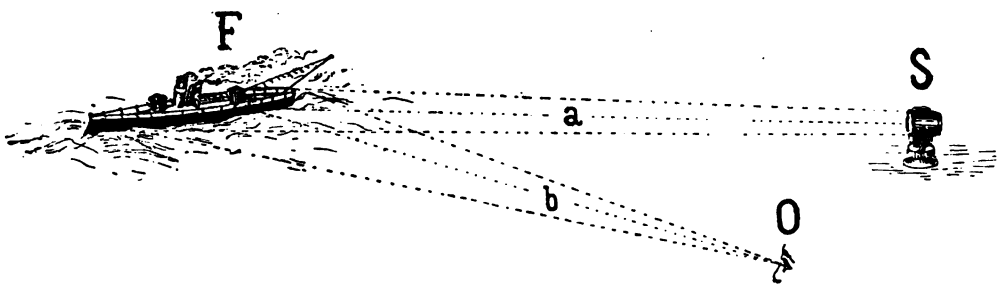


FIG. 9.

At a given distance *e* (Fig. 10) a surface of area $F = xy$ will be illuminated with an intensity h. If the total quantity of light falling on F is Q,

$$Q = h\,F.$$

At a distance e_1, the same quantity of light Q will illuminate the surface $F_1 = x_1 y_1$ with an intensity h_1, so that

$$Q = h_1\,F_1,$$

From this we get

$$h_1\,F_1 = h\,F,$$

or

$$\frac{h_1}{h} = \frac{F}{F_1} = \frac{xy}{x_1 y_1}.$$

Also by similar triangles

$$\frac{x_1}{x} = \frac{e_1}{e}$$

and $$\frac{y_1}{y} = \frac{e_1}{e},$$

so that $$x_1 y_1 = xy\frac{e_1^2}{e^2}$$

and therefore $$\frac{h_1}{h} = \frac{e^2}{e_1^2},$$

so that the intensity of illumination of a distant

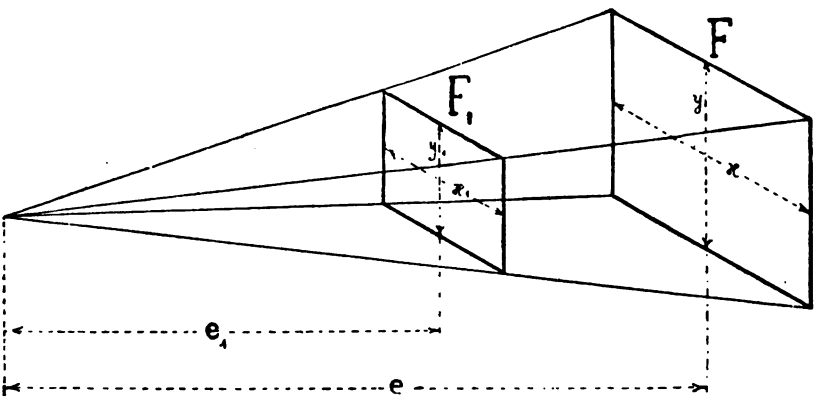


FIG. 10.

object is inversely proportional to the square of its distance from the searchlight.

When the maximum observing distance for a given distance of illumination and size of searchlight has been determined, the values for other sizes can be found by calculation in the way described above. As mirrors having a diameter of 90 cm. are now in very general use, this size may be taken as the standard. In order to obtain a maximum observing distance b, with a distance of illumination a,

a definite intensity of illumination is required for the given object. This intensity is directly proportional to the searchlight intensity ($K = C i D^2$) and inversely proportional to the square of the distance a of the searchlight, or

$$E = \frac{C i D^2}{a^2}.$$

In order to see an object at the same observing distance b equally well with another searchlight S_1 we must have $\frac{C i_1 D_1^2}{a_1^2} = \frac{C i D^2}{a^2}$; from this it follows that

$$a_1 = \sqrt{\frac{i_1 D_1^2 a^2}{i D^2}} = a \frac{D_1}{D} \sqrt{\frac{i_1}{i}},$$

that is, the maximum distances of illumination with different sizes of searchlights and for a given observing distance are directly proportional to the diameter of the mirror and the square root of the intrinsic brilliancy of the source of light. If the observing distance is equal to the distance of illumination, we may call this the *radius of action e.* The brightness of the image of the object formed on the retina of the observer's eye will be directly proportional to the illumination of the object and inversely proportional to the square of the distance, that is to $\frac{E}{e^2}$. If we substitute for E the value already found we have the brightness proportional to $\frac{C i D^2}{e^4}$.

If we wish to obtain an equally bright image of

the same object when illuminating it with another searchlight S_1, we must have the brightness proportional to $\frac{C i_1 D_1^2}{e_1^4}$,

from which it follows that

$$e_1 = \sqrt[4]{\frac{e^4 i_1 D_1^2}{i D_2}} = e \sqrt{\frac{D_1}{D}} \sqrt[4]{\frac{1}{i}},$$

that is to say, the radius of action for searchlights of various sizes is directly proportional to the square root of the diameter of the mirror and to the fourth root of the brilliancy of the source of light.

When the distances at which given objects can be perceived and examined have been determined for a searchlight of 90 cms. diameter, the distances of illumination and observation obtainable with other searchlights can be calculated without difficulty. In order to simplify this problem constants for various searchlights are given in Table 1. In columns 12, 13, 18 and 19 the radius of action, which has been determined by actual tests, is given for various objects.

The formulæ which have been given above hold for a concentrated beam. If the light is spread out in a horizontal direction by means of dispersers, the illumination of the distant object will go down in proportion to the ratio of the angle α of beam without disperser to that β with disperser. In addition the mean horizontal intensity is to be considered and not the axial intensity of the beam, as in the case of concentrated light. The mean horizontal intensity amounts to about 65 per cent. of the axial intensity.

The radius of action e_s when the disperser is used can be obtained from that e with the concentrated beam from the formula

$$e_s^4 = \frac{0{\cdot}65\, e^4\, a}{\beta} \text{ or } e_s = e \sqrt[4]{\frac{0{\cdot}65\, a}{\beta}}.$$

In Table I., columns 14, 15, 16, and 17, several values for the radius of action when using dispersers are given.

In measuring the radius of action it is further assumed that the searchlights are well handled so that the object is illuminated with the zone of greatest brightness. Only on these assumptions is it permissible to apply these constants to searchlights having unusual angles of dispersion.

For a more complete calculation there is also to be taken into account the area of the object to be illuminated, its reflecting power, and the absorption of the rays by the atmosphere. The quantity of light reflected from the illuminated object is directly proportional to its area and to its reflective power, the latter being defined as the ratio of the quantity of light actually emitted from the object to that which would be emitted if it had a perfectly white surface.

In order to take into account the absorption of the atmosphere, the apparent brightness of an illuminated object at a distance e must be reduced in the ratio $1 : (1-p)^e$, where p denotes the absorption caused by passage through one kilometre of the atmosphere.

When searchlights are being tested, the magnitude of the atmospheric absorption is usually not

TABLE I.

Diameter D of Mirror. cms.	Focal Length of Mirror. cms.	Normal Current. Amps.	Diameter of Crater. m/m	α = Angle of Reflected Beam.	$\frac{D}{D_{90}}$	$\sqrt{\frac{D}{D}}$	$\sqrt{\frac{D}{90}}$	$\frac{i}{i_{90}}$	$\sqrt{\frac{i}{i_{90}}}$	$\sqrt[4]{\frac{i}{i_{90}}}$	Relative Distances of Illumination. metres *	Radius of Action of Searchlight. For small objects. Metres.†					For large objects. Metres‡ observed at	
												With concentrated beam.	ε With angles of dispersion of 10°	20°	30°	45°	Ismid.	Nürnberg.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
35	17·5	20	9	2° 56′	0·389	5·916	0·624	0·68	0·825	0·908	860	1,530	1,000	850	770	690	7,000	4,300
40	20	30	9·4	2° 42′	0·444	6·325	0·666	0·76	0·872	0·934	1,050	1,680	1,080	910	825	740	7,600	4,700
45	20	40	10	2° 52′	0·500	6·708	0·707	0·86	0·927	0·963	1,250	1,830	1,200	1,010	920	825	8,350	5,150
60	25	60	12·1	2° 47′	0·666	7·746	0·8165	0·914	0·956	0·978	1,710	2,150	1,400	1,180	1,060	960	9,800	6,050
60	28	70	13·5	2° 46′	0·666	7·746	0·8165	0·944	0·972	0·986	1,740	2,170	1,410	1,190	1,070	970	9,900	6,100
75	31	80	15·3	2° 50′	0·833	8·66	0·9128	0·966	0·983	0·9915	2,200	2,430	1,590	1,340	1,200	1,090	11,060	6,860
90	38	100	18	2° 43′	1·000	9·487	1·0000	1·000	1·000	1·000	2,700	2,700	1,750	1,470	1,330	1,200	12,300	7,600
90	42	120	20	2° 44′	1·000	9·487	1·0000	1·018	1·010	1·005	2,700	2,700	1,750	1,470	1,330	1,200	12,300	7,600
110	52	150	23	2° 33′	1·222	10·488	1·105	1·066	1·030	1·015	3,300	3,000	1,910	1,610	1,440	1,310	13,600	8,400
150	65	150	23	2° 2′	1·666	12·247	1·291	1·066	1·030	1 015	4,500	3,450	2,080	1,760	1,580	1,430	16,000	9,850

* The distances at which searchlights of the respective diameters must be placed in order to render an object just visible when the observer's distance from the object is 2,700 metres.

† The distances at which it is possible to see whether artillery fire is too high or too low, to clearly distinguish sappers working on intrenchments, or to discover torpedo boats at sea; observer and searchlight being at same distance from object.

‡ The distances at which it is possible to distinguish large light-coloured buildings; observer and searchlight being at same distance from object.

known. The comparison of two searchlights is therefore only possible when they are examined at the same time. If, for instance, one of them is tested soon after dark and the other at midnight, quite different results are obtained with similar apparatus, or even when using the same searchlight. When it is remembered that the absorption of the atmosphere may be anything from 2 to 50 per cent. and even more, it is easy to see that the influence of this factor is of extreme importance.

From this it is clear that the radius of action furnishes an extremely unreliable measure of the capabilities of a searchlight.

We have found that the values for radius of action for two searchlights can be expressed by the relation

$$e_1 = e \sqrt{\frac{D_1}{D}} \sqrt[4]{\frac{i_1}{i}}$$

If one of the searchlights has 36 per cent. greater brilliancy than the other, it will be found that the radius of action of the first searchlight is only 100 metres greater than that of the second when the latter is 1,250 metres. In order to increase the radius of action from 3,000 to 3,300 metres, an increase of 10 per cent., it would be necessary to increase the intrinsic brilliancy of the source of light by 46 per cent.

It is very difficult to distinguish differences in distance as small as 10 per cent. at night when all surrounding objects are in darkness, and it is equally difficult to distinguish with the naked eye

TABLE II.

Diameter D of Mirror.	Current.	Voltage.	Watts.	H. E. per Watt.	Intensity in H. E. of rays incident on the Mirror.		Mean Intensity in H. E., of reflected rays.	Diameter d of Crater.	Intensification of Mirror D^2/d^2.	Intensity of reflected beam in H. E., at great distances, neglecting atmospheric absorption.	Focal length of Mirror.	Angle of dispersion.	Diam. of beam at 1,000 metres distance.	Illumination in Lux with absorption of 10·4 % per kilometer, at distances of:	
cms.	Amps.	Volts.			maximum.	mean.					m/m		metres.	1,000 m.	2,000 m.
40	20	43·5	870	4	3,480	2,780	2,500	9·3	1,854	4,635,000	180	2° 58′	51	4·57	0·93
	25	44	1,100	4·6	5,000	4.000	3,600	9·4	1,811	6.490,000	180	2° 59′	52	5·8	1·3
	30	44	1,320	4·8	6.300	5,000	4,500	9·5	1,773	8,000,000	200	2° 43′	47	7·17	1·6
45	20	43·5	870	4	3 480	2.780	2,500	9·3	2,341	5.850,000	200	2° 40′	46	5·24	1·18
	30	44	1.320	4·8	6,300	5,000	4,500	9·5	2,244	10.600,000	200	2° 43′	48	9·5	2·125
	40	45	1,800	5·14	9.250	7,400	6,660	10	2,025	13,500,000	200	2° 52′	50	12·5	2·7
60	40	45	1,800	5·14	9,250	7,400	6,660	10	3,600	24.900 000	250	2° 18′	40	22·4	5
	50	46	2,300	5·35	12,300	9,800	8,820	10·9	3,030	26,700,000	250	2° 30′	44	23·9	5·35
	60	47	2,820	5·55	15,500	12,400	11,150	12·1	2,459	27,200 000	250	2° 47′	48	24·3	5·45
75	60	47	2,820	5·55	15,500	12,400	11,150	12·1	3,840	42.300,000	310	2° 16′	39	37·8	8·5
	75	49	3,675	5·8	21,200	17,000	15,300	14·3	2,744	42,300,000	310	2° 38′	46	37·8	8·5
	90	51·5	4,680	6	28,100	22,500	20,500	16·7	2,020	42,300.000	310	3° 6′	54	37·8	8·5
90	60	47	2,820	5·55	15,500	12,400	11,150	12·1	5,532	61,000,000	310	2° 16′	39	54·7	12·25
	75	49	3,675	5·8	21,200	17,000	15,400	14·3	3,950	61,000,000	380	2° 8′	38	54·7	12·25
	90	51·5	4,680	6	28,100	22,500	20,500	16·7	2,900	61,000,000	380	2° 32′	44	54·7	12·25
90	100	53	5,300	6·05	32,000	25,700	23,130	17·5	2,640	61,000,000	380	2° 43′	47	54·7	12·25
	125	55·5	6,660	6·23	41,500	33 200	29,880	20	2,030	61,000,000	420	2° 44′	48	54·7	12·25
	150	59	8,900	6·45	57 000	45,600	41,040	23	1,530	61,000,000	420	3° 8′	55	54·7	12·25
110	150	60	9,000	6·5	58,000	46,400	41,750	23	2,287	96,000,000	520	2° 32′	44	86	19·25
150	150	60	9,000	6·5	58,000	46,400	41,750	23	4,300	180,000,000	650	2° 2′	36	161	32·25

differences in illumination of a distant object as large as 30 per cent.

The only way, therefore, of forming a true estimate of the value of a searchlight is to carry out careful photometric measurements.

In Table II. are given values of intensity obtained with various searchlights, partly by photometric measurements and partly by actual tests in the open. It is of course only possible to speak of approximate values in such a case as this.

The nature of the surrounding objects illuminated at the same time as the one under examination may have a very disturbing influence on the observations. A dark object on a bright ground is difficult to recognise when it has not some distinguishing size and form. Irregularities in the ground which cast long and sharp shadows alter the appearance of the landscape so much that even skilful observers require careful training in order to distinguish a particular object.

CHAPTER V.

TESTING OF SEARCHLIGHT MIRRORS.

SEARCHLIGHT mirrors are tested with the object of ascertaining whether the form of the mirror is sufficiently close to that required by theory, and the tests are carried out by optical methods. The deviations from the prescribed form may be of two kinds, so that two tests are necessary, namely, the line test and the zone test.

A. *The Line Test.*

If we imagine a section taken through the centre of the mirror, a curve is obtained whose curvature should vary in a regular manner from the centre towards the edge, but the curve will take a wavy form instead of a regular one if the surface has not been accurately worked.

In order to test the regularity of the curve the mirror is erected opposite a large board, on which are painted two systems of parallel straight lines at right angles to one another. The image of these lines given by the mirror, is examined or photographed through an opening in the centre of the board. If the surface of the mirror is wavy or irregular the image of the lines will also show a wavy outline as given in Fig. 11A.

The image as seen in a correctly ground mirror is shown in Fig. 11B.

With an accurately ground parabolic mirror the lines should be quite regular, but need not necessarily appear as straight nor as parallel. The line test can therefore be regarded only as a test for

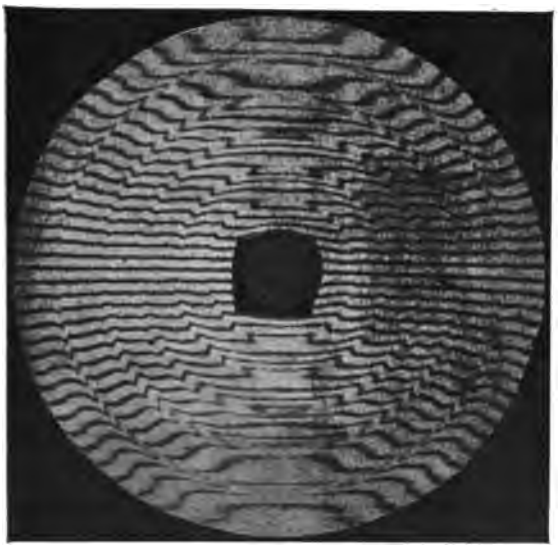


FIG. 11A.

irregularities of form. Whether the form is parabolic or not can only be determined by means of the second test.

B. *The Zone Test.*

The mirror should reflect light coming from its focus in the form of a parallel beam. It must, therefore also have the corresponding property of

bringing a parallel beam to a focus in a single point. If the form is not quite correct one part of the parallel beam will be brought to a focus in one point and another part of the beam to a focus in another point.

In order to test for such errors as these a beam

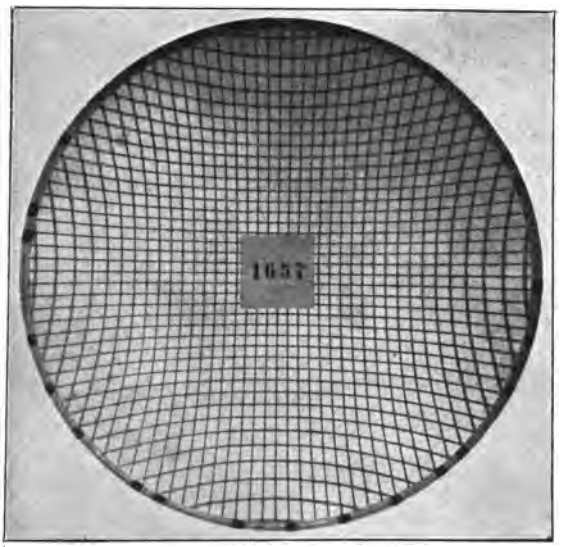


FIG. 11B.

of light from a very distant source, for instance from the sun, is allowed to fall on the mirror. The greater part of the mirror is then covered up, so that only a ring about $\frac{1}{2}$ in. wide at the edge of the mirror is illuminated. The focal point of this zone is found by means of a screen placed in front of the mirror in its axis. A similar test is carried out for

all the zones, and the same focal point should be obtained for each. Certain deviations may be observable for different zones, and these deviations give a measure of the amount by which the mirror departs from the correct form.

CHAPTER VI.

APPLICATIONS OF SEARCHLIGHTS.

In order to take into account the various applications, we shall divide searchlights and their accessories into the following classes:

A. For use in the field.
B. For use in land fortresses.
C. For naval stations or coast defence.
D. For battleships.

A. *Searchlights for Field Use.*

The value of searchlights for military operations in the field, which up till recently was questioned by some authorities, is now no longer in doubt. The searchlights and searchlight gear which have been tried during manœuvres have, perhaps, not led to the strikingly successful results expected, but recent wars have given proof that a complete searchlight equipment is indispensable.

Too much should not be asked of searchlight equipment of this kind, more particularly as very light gear, which can be easily transported, is the only kind which is of any use. A glance at the previous table, however, will show that searchlights of quite small size give fairly good results in comparison with larger and heavier types, and

apparatus with glass parabolic mirrors of 60 c.m. diameter should be considered as the maximum size which can be used in the field.

For those cases in which the power waggon giving sixty amperes, as used with a 60 c.m. searchlight, is too heavy, a lighter waggon giving a current of forty amperes may be used, and a good effect will still be obtained. The whole equipment will become considerably lighter and handier in use through the choice of this smaller current strength. For particular purposes searchlights of even 40 to 45 c.m. mirror diameter, using thirty to thirty-five amperes, will be found sufficient, requiring a power waggon for an output of about 2·4 k.w.

Power cars with steam engine-driven generators are now seldom or never made. They have been replaced by generators driven from petroleum-, or more usually petrol-motors. This development is very closely connected with the rapid increase in recent years of the use of petrol motors for motor cars. The characteristic advantages of the petrol motor, namely, readiness for use, simplicity in operation and small weight, make it specially suitable for the purpose of a transportable lighting equipment. However, as up till recently it was feared that difficulties would arise in procuring petrol, petroleum or alcohol motors used to be preferred in military circles, and were specified for such equipments.

Since the general adoption of petrol motors for motor cars and other purposes, these fears have

FIG. 12.

shown themselves to be groundless, and it is therefore to be expected that power cars with petrol motors will come into general use for military purposes.

The Siemens-Schuckert Company build for field use a very light equipment consisting of a waggon for petrol motor and dynamo, and a searchlight waggon coupled to it. The cable required for connecting the searchlight with the power waggon is carried on the searchlight waggon; Fig. 12 shows a complete equipment of this kind.

It should be mentioned here that in this equipment is also included a transportable searchlight tower for elevating the searchlight, when the searchlight itself is not fitted with an arrangement for being raised from the waggon.

These arrangements have the object of enabling the searchlight to be used to greater advantage on uneven and hilly ground. When the searchlight is raised to a height the shadows thrown in the foreground are made shorter, and the possibility of affording cover is reduced.

Fig. 13 shows such a tower elevated and with the searchlight in position.

B. *Searchlights for Land Fortresses.*

Searchlights of this type are used for a variety of purposes, the arrangements for which we may classify under three headings:—

(1) The power supply and the searchlight are both fixed.

FIG. 13.

(2) The power supply is fixed but the searchlight is movable.

(3) The power supply and the searchlight are both movable.

(1) In the first case dynamos driven by steam engines, Diesel engines or petrol motors, &c., can be used for the power supply. Paraffin motors, which so far have been built only for low outputs, are only useful for small installations.

When the searchlight is fixed in position it is so exposed to gun fire that a special protection is necessary. The most effective method has been found to be that of erecting the searchlight on a rotatable armoured stand which can be raised if illumination is required and lowered if the searchlight is to be protected (Fig. 14). In order to avoid the large openings required for the beam of light and also partly on account of the large increase of cost with larger sizes, it is not advisable to use a searchlight of more than 60 c.m. diameter. Such an installation is of use chiefly in small advanced fortresses, and a large number of this type have been carried out by the Siemens-Schuckert Company for the Belgian Government for their fortifications on the Meuse.

If searchlights of this size are not sufficient for the required purpose larger ones must be used which can be raised and lowered as before, and protection afforded not by raising or lowering the armoured cover together with the searchlight but by an armoured door over the opening.

An arrangement for protecting searchlights has been proposed by the English Officer, Colonel Bucknill, and was described in *Engineering*, 1888, p. 324. Behind the protection of a parapet a searchlight is placed at one end of a horizontal

beam which can be tilted about a horizontal axis. At the other end of this horizontal beam a plain mirror is fixed which can be turned about a hori-

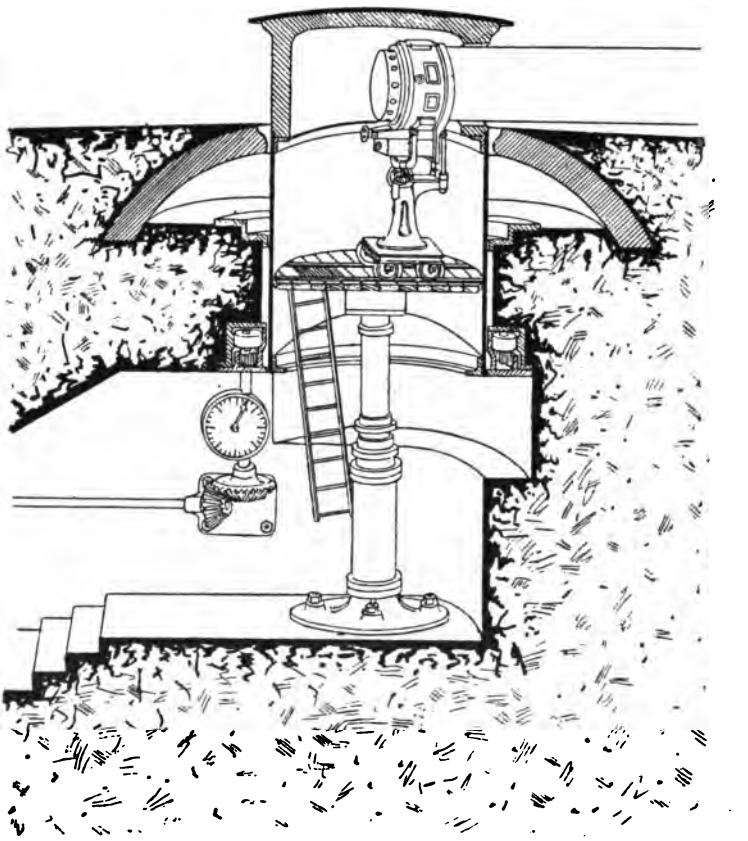


FIG. 14.

zontal axis. The latter projects over the parapet, and the searchlight below sends a beam of light to the plain mirror from which it is reflected to the country outside. The vertical beam rests with its central support on a rotatable base so that the

beam of light can be turned in any horizontal direction as required.

Arrangements of this kind would only be of use in exceptional cases since, firstly, the beam of light on reflection at the mirror loses about 10 to 30 per cent. of its brightness, and, secondly, it affords protection for the searchlight only against shots which have a horizontal flight, and dropping shots coming at an angle would be almost as dangerous for the searchlight as if it were in the open.

A very effective protection is afforded by shelters hewn in the rock or otherwise made bomb-proof, and which can be completely closed by means of iron doors. The searchlight is erected on a truck running on rails so that it can be run out of the shelter when required. Experience has shown that the distance of a searchlight is very difficult to estimate when the light is in operation, and it can, therefore, only be struck by a chance shot; if the danger becomes very great the searchlight can be run back into the shelter. Only those positions are suitable for the erection of searchlights which are situated at a good height so that they cover the foreground well, and they should not be chosen too near the battery lest the artillery be disturbed by the beam of light and the stray illumination which is always present in the neighbourhood of a searchlight. If both the power supply and the searchlight have a fixed position the current is usually carried through cables which are laid in the earth in a safe position. If the searchlight is brought

out of a shelter when in use the cables can be brought out to switch pillars (Fig. 15) in a suitable place in the entrance to the shelter. The search-

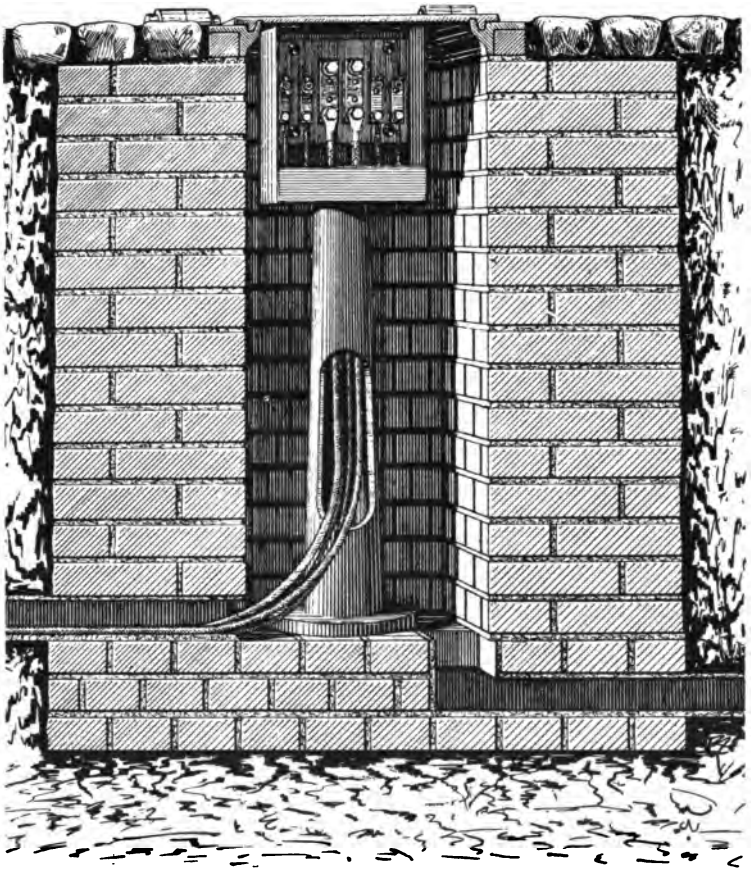


FIG. 15.

light is then connected with these switch pillars by means of short cables.

(2) If the power supply is fixed and the searchlight movable and the places where the searchlight

is to be erected are not too far apart, bomb-proof shelters can be made from which the searchlight

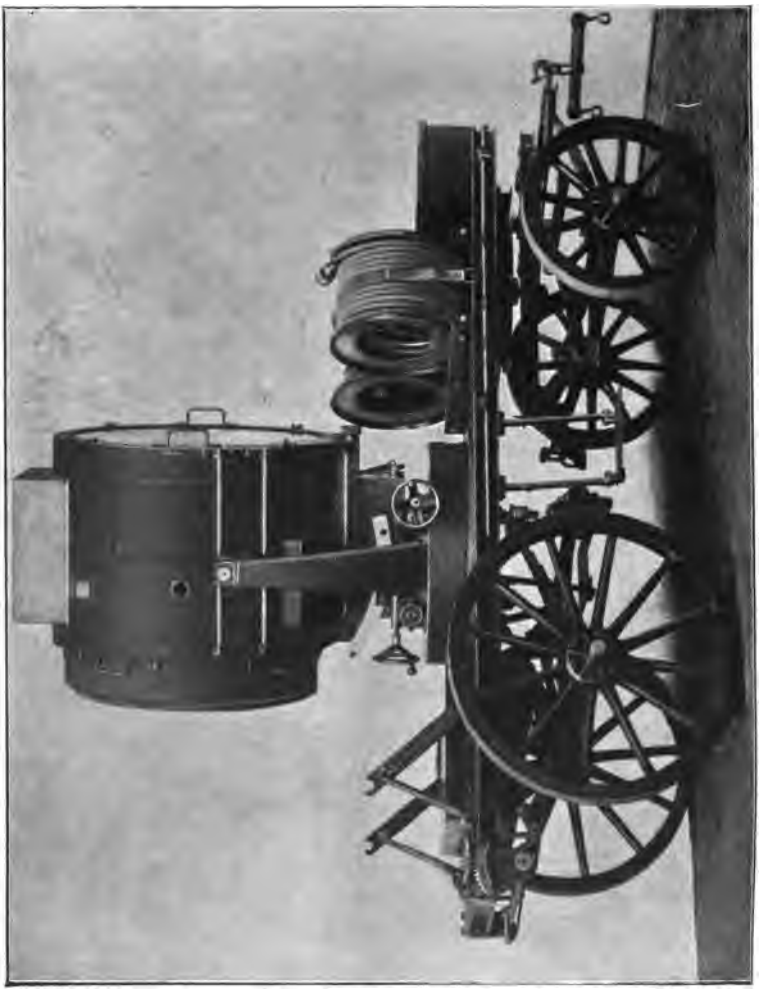


FIG. 16.

can be run out when required. When possible, the various places of erection are connected by means of a light railway. The waggon can

carry accessories, a supply of cable, &c. (see Fig. 16).

If a high situation is not to be found in the fortress, a transport waggon may be used, fitted with a platform which can be raised. Such

FIG. 17A.

waggons can, on account of their great weight, only be used if the nature of the ground is favourable. In unfavourable cases waggons may with advantage be used in which the searchlight body only is raised. In Figs. 17A and 17B a searchlight of this kind, of 90 c.m. mirror diameter, is shown fitted with elevating

screws on a waggon which serves at the same time to carry the cable. This arrangement has the advantages that the searchlight is at a height when in use and that when lowered the centre of gravity is so low that there is no danger of the

FIG. 17B.

waggon overturning, and the handiness in use is consequently increased. Electric motors for remote control can also be fitted to these transportable sets. Cables for the lamp and for the motors can be carried on the waggon. Figs. 18A and 18B show a searchlight with a mirror 60 c.m. diameter and 1 metre elevation distance.

As in the first case, the cables can be laid

completely in the ground. A switch pillar is then to be erected in a masonry shaft at each point where the searchlight may be required. The searchlight

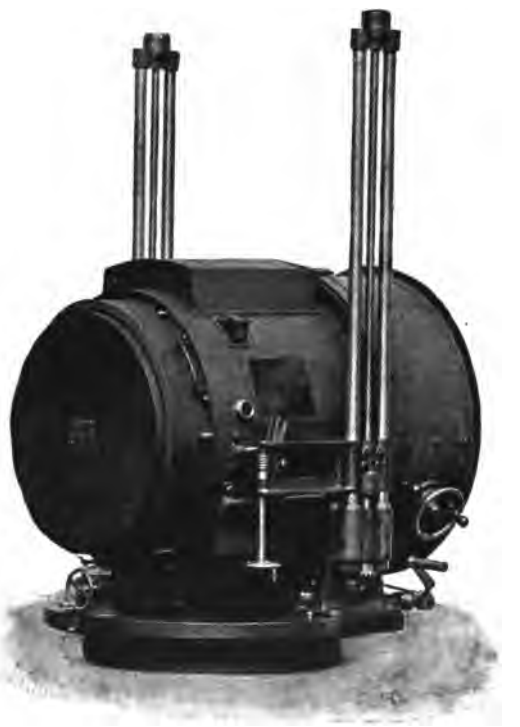


FIG. 18A.

can be connected up by a cable of suitable length.

Another way of arranging the installation is to run out the whole cable, only when required. In this case well insulated and armoured rubber cable is to be chosen. For running out this cable the Siemens-Schuckert Company recommend a specially

constructed cable drum (Fig. 19). If the distance between the machines and the searchlight is large, several cable drums are connected in series, and

FIG. 18B.

the ends of the cable are connected by suitable couplings.

(3) If a fixed point for erection cannot be found for either power supply or for searchlight a power

waggon must be used. For such installations the same considerations are in general applicable as in the previous cases, but as a rule larger searchlights, and therefore larger power waggons with a higher output, are required.

The same arrangement, as shortly described under (2), will serve for transport of searchlight and cable. In cases where the power waggon and

FIG. 19.

searchlight have to be set up at fixed points, and where sufficient protection cannot be arranged for so that the apparatus must be moved away when threatened by gun fire, the cable can with advantage be laid underground and taken to connection pillars at the required points; connections can then be made with short lengths of flexible cable.

If the power waggon and searchlight have to be moved from place to place, underground cables

cannot be used. The cables are then run out only as required, and the arrangement described under (2) is sufficient.

In land fortresses, as in the case of field operations, the concentrated beam of light is most generally used. In the case of advanced forts, particularly in hilly districts where it is frequently required to illuminate certain portions of the field of view, which as a rule are not at a very great distance, the dispersed beam, spread out horizontally so as to illuminate the important area over a wide range, can be used with advantage. To obtain such a beam glasses called dispersers are used, and these can be made to give various degrees of dispersion as required.

C. *Searchlights for Coast Defence.*

The difference which we have already drawn between searchlights with concentrated beam and those with dispersed beam is here of particular importance. Large coast defence batteries which have to protect a given place against night attack should have at least one searchlight which is used with concentrated beam only. This searchlight should be situated towards the side and outside the battery. It should be fitted with motors for remote control for giving both turning and tipping motions, and should be capable of being controlled by an observer situated in the battery itself. The searchlight should be mounted on a truck to run on rails, and

when not in use should be run back into a bomb-proof shelter.

In addition to this searchlight there should be others fitted with dispersers for the illumination of the water where mines are placed. The number of searchlights used should be arranged according to the number and extent of the mines and the distance of the observer. Searchlights which are used to give a broad beam for near illumination are always fitted with dispersers. The magnitude of dispersion required should be arranged to suit local conditions. With a given size of searchlight the data for a particular case can be worked out from the tables which we have already given. In general, mirrors of not less than 90 c.m. in diameter should be used for coast defence batteries, whether they are for use with concentrated or dispersed beam. Those giving a concentrated beam can have a diameter even as large as 110, 120 or 150 c.m. with advantage.

Since those giving a dispersed beam have to fulfil a quite special purpose, they can be permanently erected at a given point ready for use, but they are in that case specially liable to damage from the enemy's fire, and it is necessary to protect them in some suitable and efficient manner. For this purpose the searchlight should be erected behind armour plates and only run out on rails into the open when required, or the armour plates may be furnished with openings which allow the light to pass through. Behind these openings a

grating can be arranged, consisting of strong steel bars situated in the dark spaces between the separate

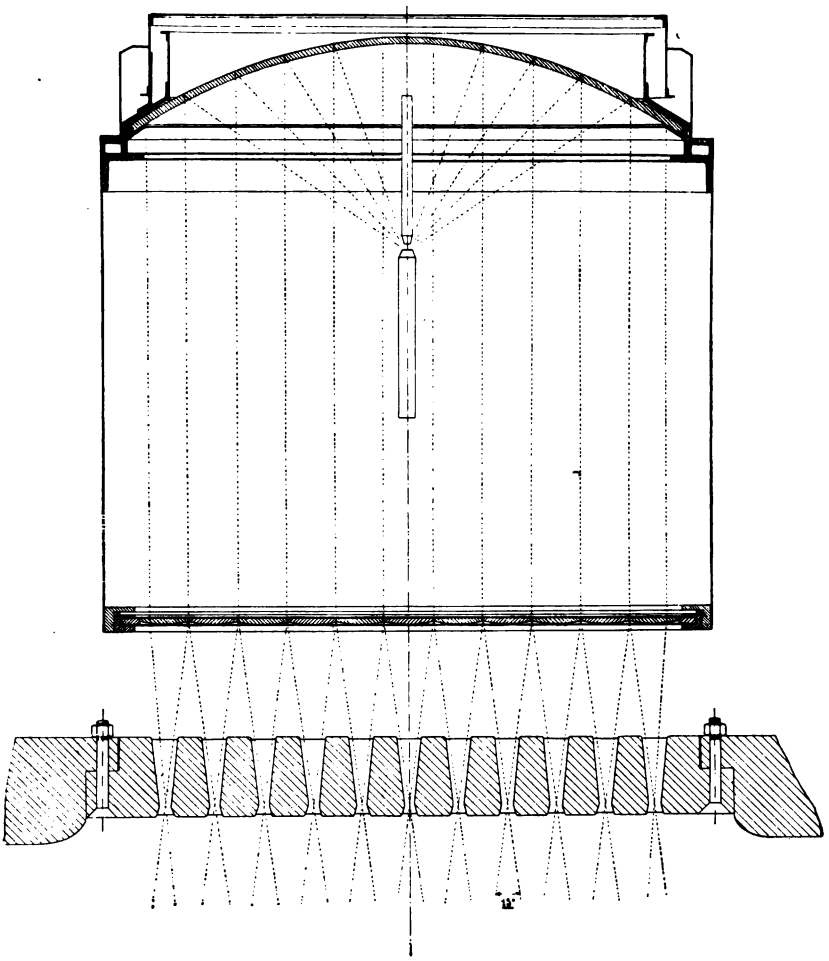


FIG. 20.

bands of light coming from the disperser, as shown in Fig. 20. The parallel rays coming from the searchlight are so refracted to the foci of the

separate plano-convex cylindrical lenses of which the disperser is made up, that dark spaces exist between the separate beams of light, in which these steel bars can be placed.

Even if these gratings are not sufficiently strong to withstand direct fire, yet they will still afford sufficient protection against fragments of shells. To obtain still better protection when not in use an armour plate can be placed in front of the grating.

D. *Searchlights for Battleships.*

The importance of searchlights for military purposes has been already recognised, but in the case of battleships the part played by searchlights is even more important.

It is only through the aid of searchlights that it is possible to repel torpedo boat attacks on dark nights. The blinding beam of light rightly handled by the defenders increases the difficulties of attack quite considerably and has a demoralising effect on the attackers. The pupil of the eye, which is widely opened owing to the darkness, allows such a quantity of light to fall on the retina when the searchlight beam is turned on to the torpedo boat that the retina becomes over-excited, and the attacker is incapable of at once seeing clearly again, even when the beam of light has been turned away. If the light is turned on a second time before the eye has had time to accommodate itself to the darkness again, it has such a demoralising effect on the

attackers that only a strong sense of duty, combined with a thorough training, will enable the attack to be carried out.

The fact that on a battleship the whole installation must take up only little room is not to the advantage of the use of searchlights; the greater care must, therefore, be taken in the arrangement of the accessories and in the erection and handling of the whole equipment.

The searchlights can only be quite satisfactory when everything connected with the installation is working in a proper manner. The most important items are :—

(1) The dynamo.
(2) The cables and regulating apparatus.
(3) The handling of the installation.
(4) The searchlight itself.
(5) The method of erection.
(6) The transmission of orders.

All these must be in an efficient condition.

In planning an installation, conditions are often laid down which lead to irregularities in the service: the machine should be light, and take up the smallest possible space, and only a very small space can be spared for the attendants. These are the requirements usually specified, and are a constant cause of trouble. Small steam engines running at high speed are loaded up to their limit of output, so that the smallest overload causes a drop in the speed and voltage of the dynamo, and finally unsatisfactory running of the arc.

In choosing a dynamo care should be taken to select the voltage which is most suitable for the lamp. This is usually 25 per cent. to 30 per cent. greater than the voltage at the lamp terminals. The excess of voltage is then used up in the so-called steadying resistance. If this resistance is of too small a value, small variations in the voltage have a marked effect on the arc, while if chosen large enough the resistance produces great steadiness. For this reason, even with small current strengths such as are used for lamps in ordinary installations, a steadying resistance has still to be used, and this is even more necessary for searchlights on battleships. In most countries a voltage of 75, or more usually 80, is chosen for the installation. If the voltage is too low the arc becomes unsteady, even with the smallest irregularity in the carbons. Jumping, hissing and unsteadiness in the arc cause a corresponding flickering in the beam of light and make the searchlight at such a time unsuitable for its purpose. This is most noticeable when heavy currents are used. In order to get perfect burning of the arc — and on this the whole success of the installation depends—currents of more than 120 amperes should not be used on board ship.

From the tables given above it will be seen that the current strength does not have such an effect on the intensity when the beam is concentrated as is believed by many people. Some caution should therefore be exercised in the choice of a current

strength, and only those values should be used which experience has shown to be most suitable.

The dynamo formerly used for searchlight installations was always a compound machine. It is now usual to employ a rotary transformer supplied from the ship's mains. It is then unnecessary to use a special steam engine, and by means of a special system of connections the arc will burn perfectly with only a very small steadying resistance.

Alternating current is quite unsuitable for searchlights. The double crater which is formed with an alternating current prevents the production of a uniform beam of light, and also makes use of the energy supplied in a very inefficient way. Also it is very difficult to obtain a quietly running arc with the carbons horizontal when alternating current is used.

Into the question of the cables to be used we can only enter very shortly. Experience which has been obtained in other branches of electro-technics and the conditions holding there can be applied at once to searchlight installations. Only cables having the best insulation and efficiently protected can be used. Their section, and also that of the fuses, must be liberally chosen, since the current remains for a considerable time above its normal strength when new carbons are used. If this precaution is not taken, breakdowns owing to blowing of the fuses are unavoidable.

The steadying resistance which we have

mentioned above as necessary, particularly in installations of old design, can be made either of a fixed amount or can be made adjustable. If it has a fixed value it can be erected at any suitable point in the circuit. For high current strengths the steadying resistance is frequently made adjustable, so as to be able to compensate for variations in the voltage. In the neighbourhood of the resistance a voltmeter must be arranged which shows the voltage supplied to the lamp. In the machine room an ammeter also must be inserted in the circuit. Adjustable steadying resistances must be placed either near the machine or preferably close to the searchlight. If such a resistance is inconveniently large it can be divided into two parts, of which the greater part is fixed in value, and can be placed at any point required. The steadying resistance must be able to carry an overload of 20 to 30 per cent. in current without overheating.

A well-trained staff is the first condition for success with a searchlight installation. The latter is made up of complicated apparatus each of which requires careful study. If everything is kept in thoroughly good condition one can do with a less well trained staff, but as soon as any chance damage or breakdown occurs which is not at once evident, serious mistakes can be made if expert examination is not available. Practice and training in searchlight operations cannot be too carefully carried out. The staff must consist as far as possible of trained mechanics, and those who have

had some experience with electrical apparatus are, of course, to be preferred.

A regular course of instruction given every week, together with actual searchlight tests, should certainly be carried out. If the ship is out of service for a long time the following work should be carried out before going into commission :—

(1) The steam engine, if one is used, should be taken apart as far as the space available will allow and, in any case, all internal and external parts which might become rusty must be examined and carefully cleaned.

(2) The dynamo or rotary transformer, as soon as shut down, should be cleaned from dust and dirt. The brushes should be attended to and replaced where necessary. The commutator must be cleaned and polished with emery cloth till quite smooth and in perfect condition. If the commutator has been damaged by sparking or is out of truth it should be turned up, and for this purpose special tools should be kept in stock. After turning up, it should be polished with emery cloth. Each time it is started up after standing some time the commutator should be attended to in this manner. Too much care cannot be taken to prevent dangerous sparking occurring at the brushes, and this must be secured if necessary by shifting the brushes when the load changes. Further, all the instructions which are supplied by the manufacturers for keeping the installation in good order must be followed exactly.

(3) Before going into commission the cables must be examined to see that their insulation from the ship is perfect. The methods of testing are so well known that we need not go further into them here. Any defect in the insulation is to be carefully attended to.

(4) The searchlight itself should be completely taken apart. All the contact surfaces are to be cleaned from dirt or from rust. If electric motors are used their commutators must be put into good order as described above, and the brushes renewed when worn. All the glasses are to be cleaned with the utmost care, but scratching must be carefully avoided; the cleaning material used must, therefore, be perfectly free from dust. In all particulars the instructions which are issued by the searchlight manufacturers must be carefully followed. Special care should be taken that the lamp works perfectly. Hand regulation should never be relied on, as in the most important moments the attendant has to give his complete attention to the carrying out of orders so that he cannot pay attention to the fine adjustment of the carbons. It should certainly be required of the attendant that he should be so familiar with the method of operation of the regulating mechanism of the lamp that if at any time the lamp should work unsatisfactorily he should be able at once to find and remedy the defect. This can only be obtained by regular instruction and training of the staff.

If we now consider the searchlight itself, the

first question which arises is which size of searchlight should be chosen. In order to answer this question we must first consider what conditions illumination from a battleship has to fulfil. It should first of all be possible to detect an enemy's ship at the greatest possible distance, and in the second place it should be possible in case of torpedo boat attack to illuminate the surface of the water over a large area horizontally so that quick firing guns can repel the attack in time. Thirdly, the searchlight should be suitable for serving as a signalling apparatus to transmit commands to great distances; and fourthly, to illuminate the immediate neighbourhood for landing parties or when passing through narrow waterways. In this section we have to consider the first two points only, the other requirements can be easily fulfilled by suitable use of the same gear.

Artillery and illumination from a battleship have in some respects to fulfil the same office. On the one hand we have the beam of light and in the other the artillery fire, which is to reach the enemy's ship. Artillery makes use of various methods for distant and for close firing, and the question presents itself whether the same searchlight is equally suited to both distant and near illumination. In order to obtain an effective illumination with a searchlight to a great distance, it is necessary that the beam of light should be as concentrated and as well defined as possible. The angle of the beam must not be too great lest the immediate

neighbourhood be illuminated by stray light, in short, the searchlight must possess all those properties which we have already specified for distant illumination. If now the same apparatus is to be used to illuminate the immediate neighbourhood when a torpedo boat attack is threatened, the beam of light must be spread out as much as possible in a horizontal direction, but this spreading out must only be carried so far that even with the decreased illumination the radius of action obtained is sufficient. To obtain this extended beam, dispersers may be used which, in case of need, can be substituted for the plain glass of the searchlight. Changing the glasses takes much time and is difficult when large searchlights have to be dealt with, particularly when the space available is limited and perhaps a strong wind is blowing. When the watch, whose duty it is to observe the immediate neighbourhood, can observe a torpedo boat only with difficulty with a dispersed beam, it is of the greatest importance to direct the attention of the gunners to the suspicious object, and this is best achieved when a more intense beam can be at once directed on the object which they have observed. If it were necessary to substitute a plain glass for the disperser in order to do this much valuable time would be lost, and the torpedo boat in the meantime would either have come so near that it might have been able to discharge a torpedo, or would have had time to get away. The desire of having, when required, either

a concentrated beam or a dispersed one led the firm of Schuckert to the construction of the double disperser, which was first used in the German Navy.

With this innovation it was made possible to produce at will either a closed concentrated beam of light or to pass to any degree of dispersion up to 45°. The searchlight could then at once be used either for near or for distant illumination.

In cases where only a few searchlights can be erected on board, those fitted with double dispersers are to be preferred to any other construction. Only when it is possible to erect a large number of searchlights would different constructions be chosen for near and for distant illuminations. We should then have for distant illumination searchlights with a plain front glass and for near illumination searchlights fitted with a single disperser only. The apparatus would be thereby considerably simplified, and the amount of attention required would be correspondingly decreased.

Grave mistakes were made in the early days in the choice of places for erection. Erection in the neighbourhood of the observer is to be avoided, as the latter would then receive too much direct light from the beam to be able clearly to distinguish distant and feebly illuminated objects.

If the Commander of a ship has to put up with such an arrangement he will have to chronicle failures only too often, and will, therefore, never regard the use of searchlights with favour. In choosing a point for erection, it is above everything

necessary to select such a position that the angle between the searchlight, the object and the observer, is as large as possible. As the distances available on board ship are extremely small, every foot of space must be made use of and nothing left untried to obtain a position for the searchlight as far as possible from the observer. If there are a large number of searchlights on board, it is advisable to provide for the two kinds of searchlights separately; those giving a dispersed beam should be placed as far as possible below the observer and close to the water line, those giving a concentrated beam as high as possible and preferably on one of the masts.

The transmission of commands by searchlights is a matter of some difficulty on the sea, just as with military manœuvres on land. Even in times of peace misunderstandings may occur in manœuvres which prevent the prompt carrying out of orders, and the difficulties must be much greater in case of war when all one's forces are tested to the utmost; the operator near the searchlight cannot see whether he has illuminated a particular object or not, and if the latter is to be followed at all the commands of the observer must be exactly followed. If the light is turned too quickly or too slowly the object is often lost, and it is difficult and often impossible to find it again. Bells, speaking tubes, and telephones are very useful but still do not quite fulfil all the requirements. With searchlights for near illumination which are fitted with dispersers and which cover a large field the above arrangements answer

perfectly, as the object remains in the field of view even when the light is turned quickly; but those for distant illumination are much more satisfactory when directed by the observer himself, and a means of doing this can be provided by means of electric control.

Motors which operate the searchlight through suitable gearing about vertical or horizontal axes provide the possibility of directing the searchlight as required from any distance. The apparatus can be made suitable for giving a backward or forward motion, and also for altering the speed within certain limits. Such electric control works perfectly when everything is kept in good condition. The contact surfaces of the slip rings must be kept perfectly clean and the motor be kept in good order. After standing unused for a long time the searchlight should be taken to pieces before being used again, in order to examine and clean the parts in question. Only when all the parts are in thorough working order can a good result be obtained with certainty.

A reliable source of power, a carefully laid system of cables, a well-trained and well-instructed staff, a searchlight of as serviceable a type as possible, placed in a well-chosen position, and certainty in the transmission of orders are essential to obtaining a completely satisfactory result.

CHAPTER VII.

DETAILS OF CONSTRUCTION.

We shall first describe in some detail the simplest form of searchlight which is used in fortresses and in the field.

Searchlight with Shunt Lamp (Simple Type).

Figs. 21A and 21B show an old type of searchlight as made by the Siemens-Schuckert Company, while Figs. 22A and 22B show a later pattern made by that firm.

The searchlight consists essentially of the following parts:—

(1) Searchlight body with parabolic glass mirror, horizontal lamp, lamp adjusting and carbon adjusting gear and front glass.

(2) Turntable with arms for carrying the trunnions which support the searchlight body, and hand gear for the turning and tipping motions.

(3) Base with ball bearings and supports for the slip rings.

The cylindrical body is made of sheet metal strengthened at both ends with stout angle iron rings. The ring at the back of the body supports the parabolic mirror, and that at the front carries a door fitted with a glass which is built up of narrow

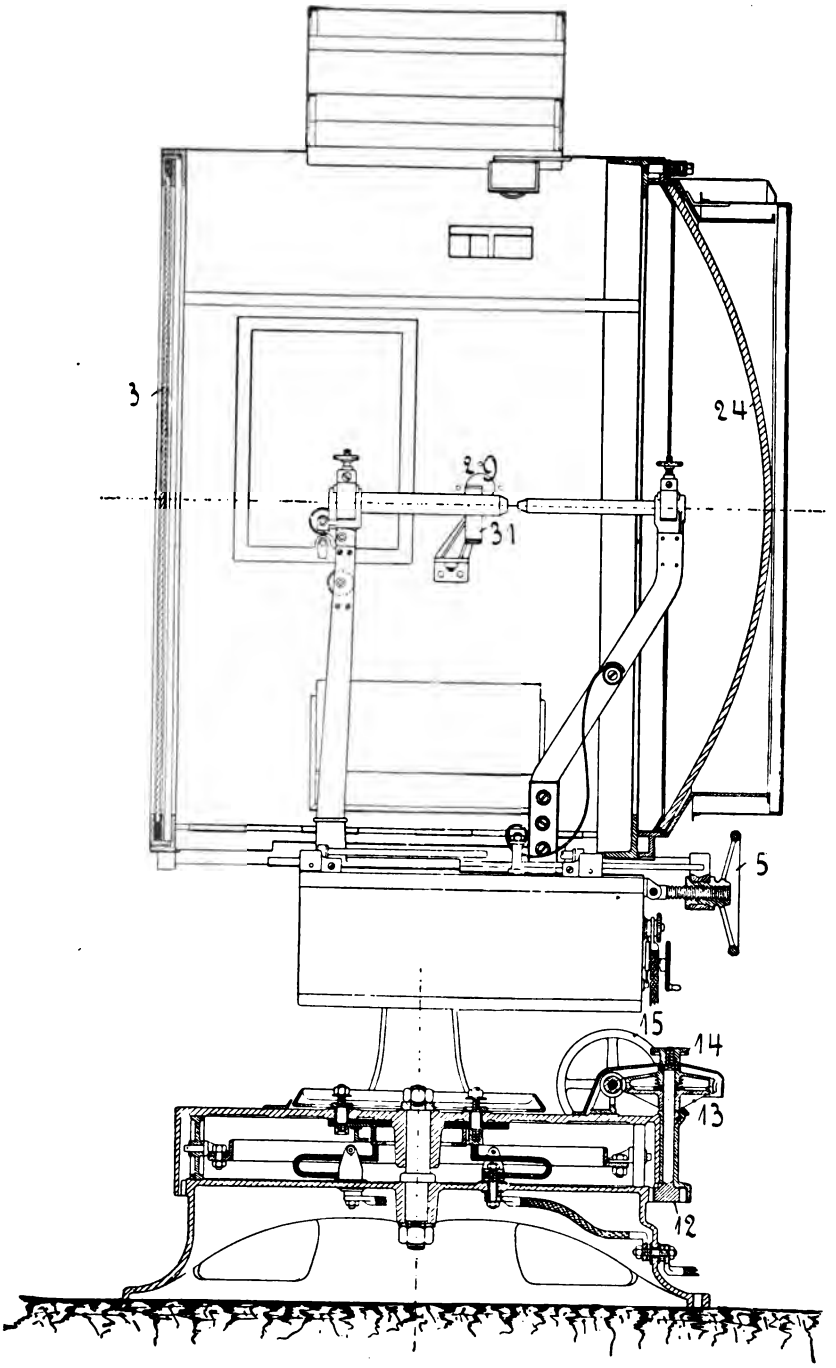


FIG. 21A

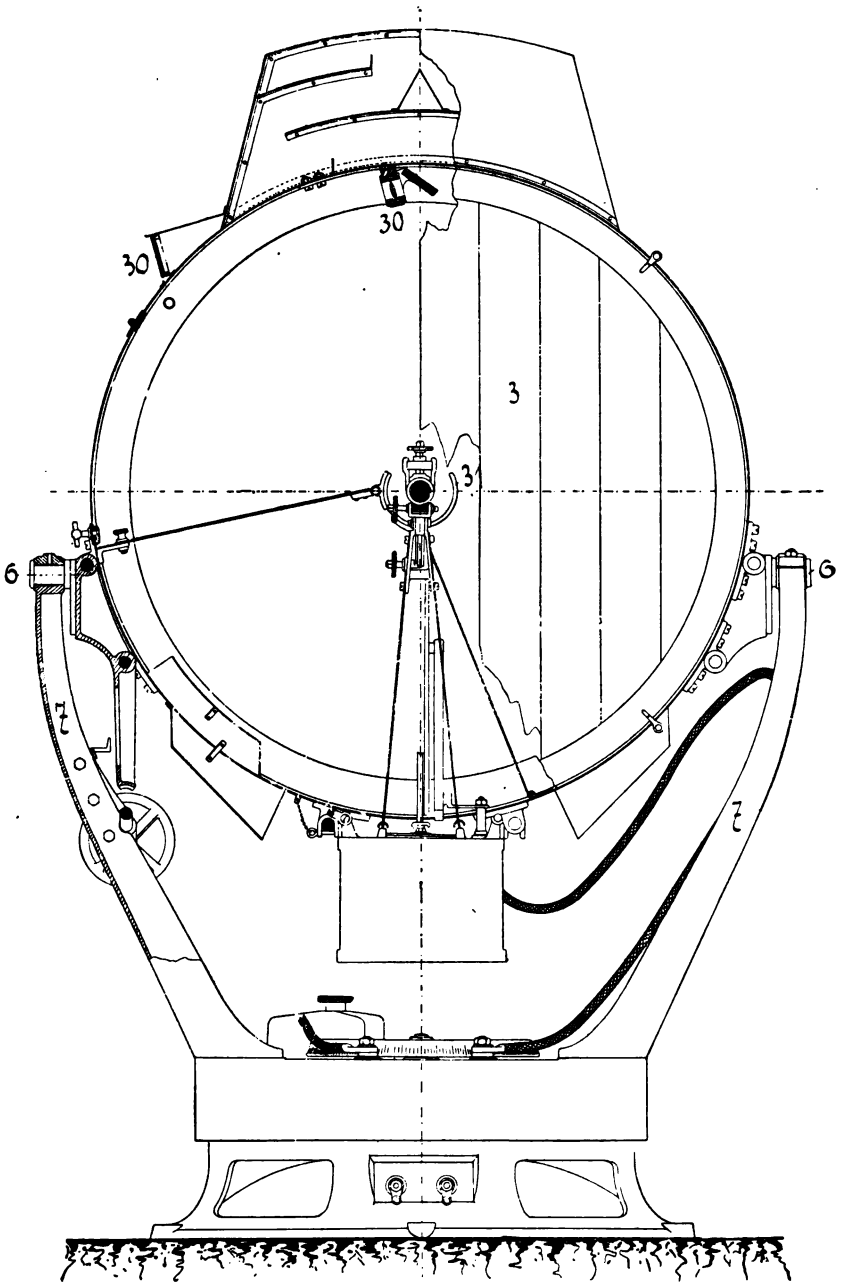


FIG. 21B.

strips. The lower part of the body has a slit parallel to the axis, through which the arms of the horizontal lamp project, and which allows the position of the lamp to be adjusted. In order to avoid overheating of the mirror and searchlight body ventilation slits are provided above and below, so that the hot air can escape at the top and be replaced by cool air from below. These openings are fitted with baffle plates and cowls, so that rain cannot enter, and at the same time no stray light appears outside.

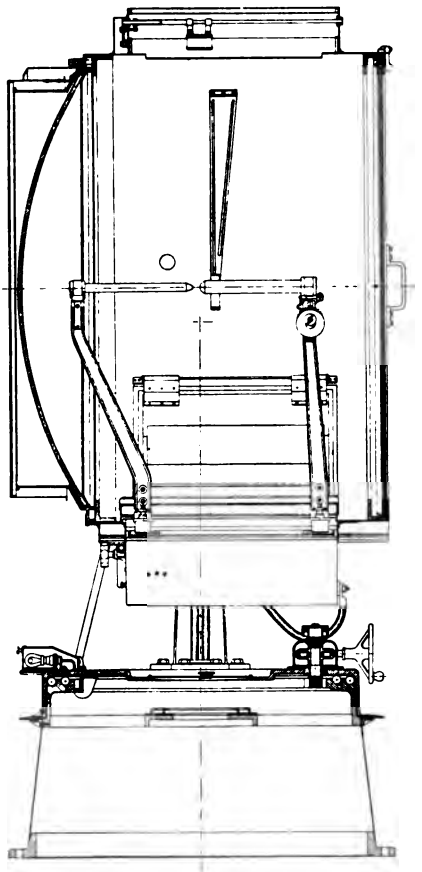


FIG. 22A.

In order to give access to the inside for cleaning and for fitting new carbons, doors are arranged at the sides which can be either hinged or made to slide open.

Observation holes (29) with dark glasses are

provided, through which the arc can be directly observed. Also a small camera obscura (30),

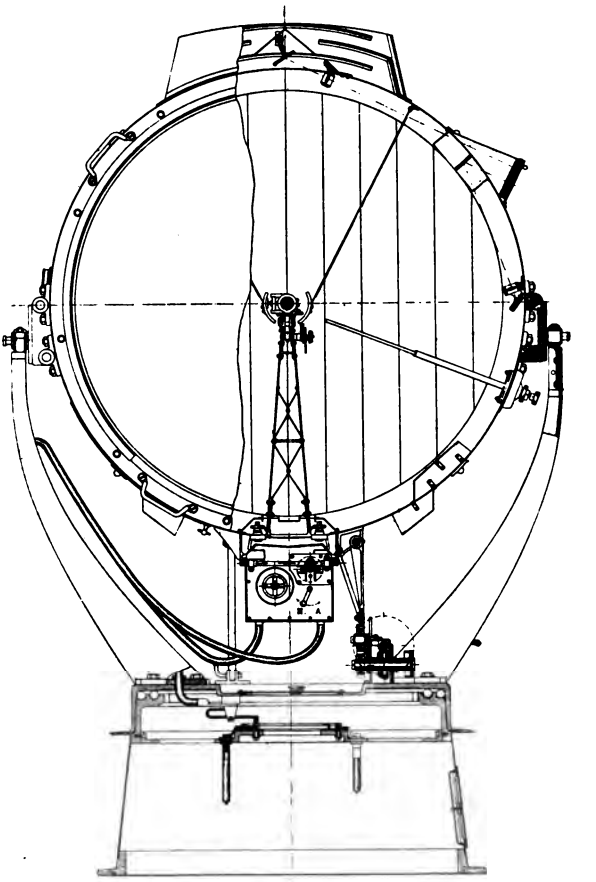


FIG. 22B.

similar to a ground glass view-finder, is fitted, which enables the form of the arc and carbons as seen from above to be examined. In the larger sizes of searchlights a second ground glass screen

enables the arc as viewed from the side to be examined at the same time.

The searchlight body has two trunnions on which it is exactly balanced. These run in the bearings carried by the side arms and allow a "tipping" motion of the body. This enables any point in a vertical line to be illuminated. The motion is obtained by turning a hand wheel keyed to a spindle carrying a worm, the latter gearing with a worm wheel on the searchlight body. A steady motion is thus obtained.

The side arms mentioned above are carried on a turntable which can be rotated about a vertical axis. The table is supported on two sets of ball bearings, one for supporting and the other for centreing.

The table, with the arms and searchlight body it carries, can be freely rotated on the base. The base has an internally projecting rack in which gears a pinion carried by the table. The rack and pinion give a means of finely adjusting and fixing the position of the searchlight. The pinion can also be operated by hand if a catch is released.

The current is led in through terminals on the base to insulated slip rings; insulated brushes are carried by the table and bear on the rings, and the current passes through these brushes to flexible cables connected to the lamp terminals.

The lamp shown in plan and side elevation in Fig. 23A, and in section and end elevation in Fig. 23B, is designed for automatic working, but can also be adjusted by hand.

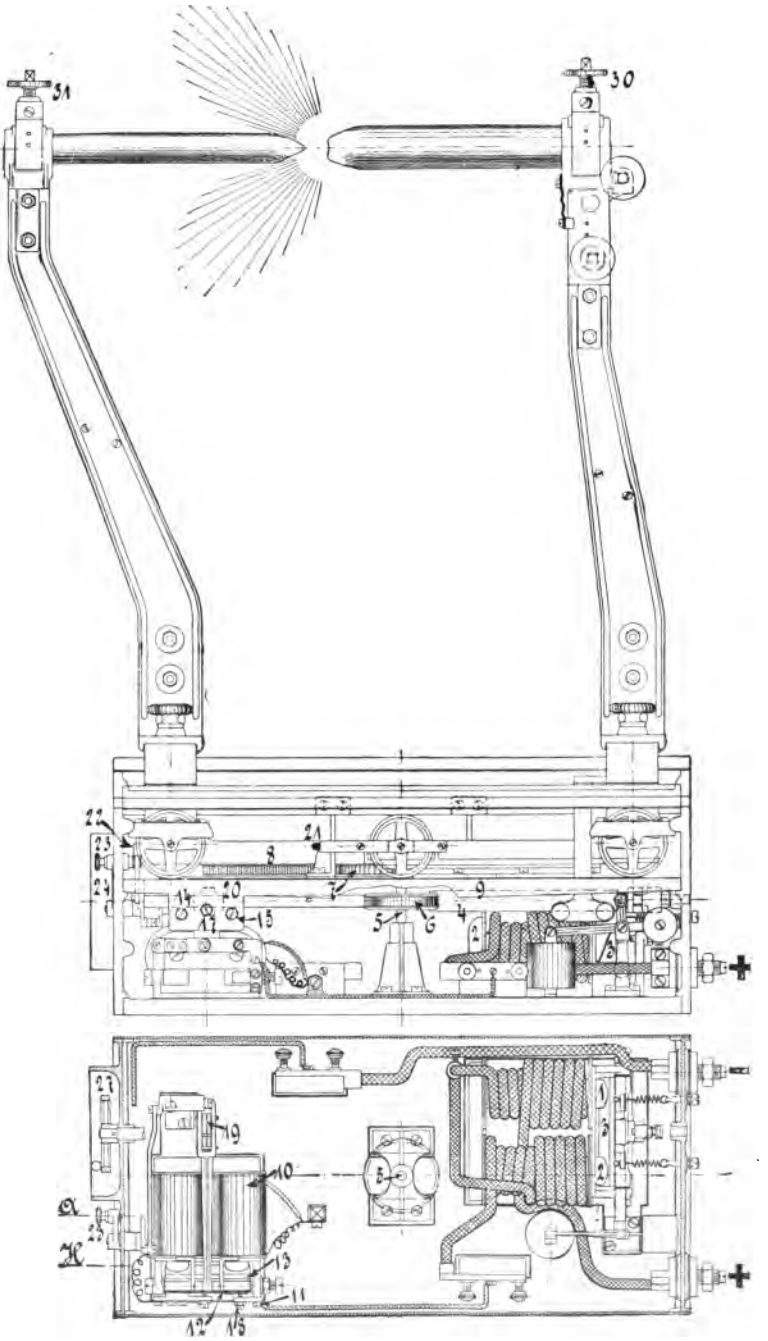


FIG. 23A.

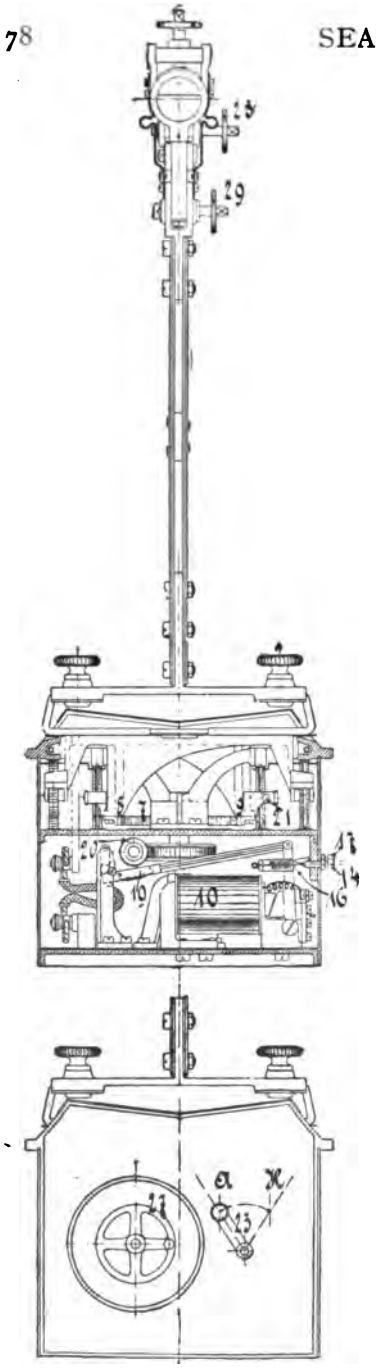


FIG. 23B

The mechanism for automatic running consists essentially of two sets of electro-magnets, of which one is used to strike the arc when the current is switched on and the other feeds the carbons when the arc is burning. The coils of the arc striking magnets (1 and 2, Fig. 23A) are series windings which carry the main current. A soft iron armature (3) on pivot bearings swings in front of the magnets and is held back by adjustable spiral springs. A forked continuation of this armature gears with a spindle and worm (4) in such a way that the latter must follow the movement of the armature.

To a vertical spindle (5) are fastened a worm wheel (6) and a pinion (7); the latter gears

with the two racks (8) and (9), which are supported on easily movable carriages. These carriages carry the arms which at their upper ends have the clips for holding the horizontal carbons. The current is conveyed through flexible leads direct to the arms and so to the carbons.

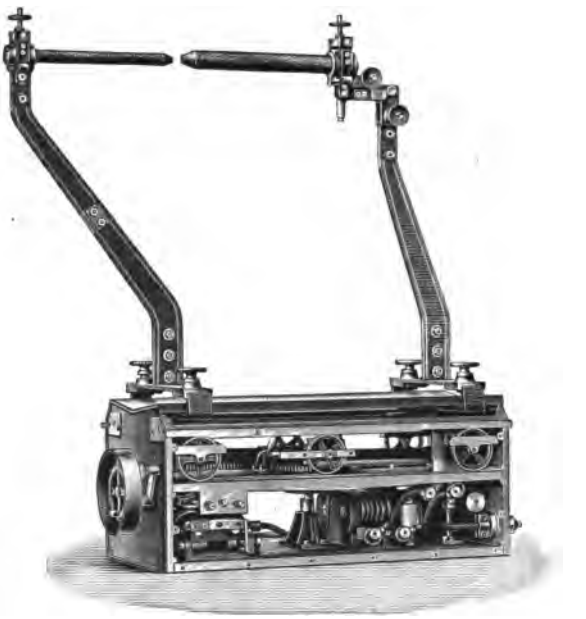


FIG. 23C.

The feed magnet (10) also has a movable armature (13) on pivot bearings. The magnet support carries an insulated contact screw (11) and the armature (13) which is fitted with a contact spring (12). The armature (13) is drawn back into contact with the stop (17) by two screws (14) and (15), and the spiral spring (16), and at the same time the contact spring (12) is drawn into

contact with the contact screw (18). The contact spring and screw and magnet winding are in shunt with the carbons. The circuit is broken as soon as the armature (13) is pulled in by the magnet (10) beyond a certain point and is re-made when the armature is drawn back by the spring (16). A ratchet (19) is connected to the armature; when the armature is attracted the ratchet slides over the ratchet wheel (20) on the worm spindle (4); when the armature is released it turns the ratchet wheel and causes the worm spindle (4) to turn. This motion is transferred by the worm wheel (6) to the toothed wheel (7) and the carbons are thereby brought closer together. If the carbons are not in contact when the current is switched on the feed magnets come into action, armature (13) is set into rapid motion by the continuous opening and closing of the circuit, and by this means the ratchet wheel (20), the worm (4) and the toothed wheel (7) are turned and the carbons are brought together. As soon as they come into contact the current in the feed magnet (10) is no longer interrupted, and the arc striking magnets (1) and (2) are strongly excited. The armature of that magnet is therefore attracted and moves the worm spindle with worm wheel and toothed wheel, so that the carbons are separated and the arc is formed.

As the carbons burn away the voltage across the arc increases and the feed magnets become more strongly excited until the pull on the armature overcomes the tension in the spiral spring (16), so that

the current circuit is interrupted by the contact breaker. The armature then springs back and the ratchet (19) the ratchet wheel (20) and the worm wheel and gear wheel are so moved that the carbons are drawn together again.

The amount by which the carbons are brought together is very small for each motion of the armature in consequence of the worm gearing, and the movements follow at such short intervals that the feed is quite steady.

When the carbons become burnt away beyond a certain point so that the support comes to its end position, the current is broken in the feed magnets (10) through the lifting of a spring operated by a pin (21) on the support of the positive carbon (9). The magnets (10) then cease to act and the arc is extinguished.

In order to bring the hand feed into action the lever (23) at the back of the lamp is changed from position A to position H, so that the current circuit of the feed magnets is broken by drawing away the contact block (24) from the two springs. The position of the carbons can then be altered by turning the handwheel (27). (See also Fig. 23c which shows a side view of the lamp when opened up.) The adjustment of the crater to the focus of the mirror is brought about by turning a hand-wheel (5) which operates a screwed spindle fixed to the lamp. When the position has once been adjusted a mark is made on the viewing apparatus (30) already described, which shows the correct

position of the crater. The position of the crater must always be adjusted to this mark in case the carbons burn irregularly or if they are of unequal length.

When using horizontally arranged carbons for the searchlight lamp the arc tends to be drawn upwards by the draught coming from the ventilation openings; this would cause the crater to burn obliquely in a short time, so that the mirror would not be used to its best advantage since the lower half would not then be fully illuminated. In order to prevent this the firm of Schuckert first tried placing the negative carbon rather lower than the positive. Since the year 1888, however, a split iron ring (31) has been arranged round the positive carbon and just behind the crater. This ring becomes magnetised by the current and a magnetic field is thus produced at the arc, which when correctly proportioned depresses the arc by exactly the amount that it tends to rise on account of the upward draught. This arrangement is to-day used by all designers who have adopted the horizontal lamp.

As the carbons burn, irregularities appear which cannot be avoided even in the best designed lamps. It is therefore necessary to adjust the carbons from time to time. In order to be able to do this quickly and easily the Siemens-Schuckert Company use an arrangement for adjusting the carbons which can be operated from outside, so that all the disadvantages are avoided which were formerly met with when it was necessary to open the casing for

this adjustment. By turning a screw and an eccentric it is possible to adjust the positive carbon in the vertical and in the horizontal planes. The screw and eccentric are attached to spindles, one contained within the other, which pass to the outside, and can be operated by two small milled heads outside the casing.

Remote Control.

We have several times mentioned remote control by means of electric motors, particularly in the case of searchlights for use with a concentrated beam. This arrangement allows the direction of the beam of light to be adjusted by a controller placed at any desired distance away and can be attached to any searchlight. We shall therefore give details of the arrangement as applied to such a searchlight as above described. It is illustrated in Figs. 24A, 24B, and 24C. In order to obtain the turning and tipping motions of the searchlight (in horizontal and vertical planes respectively) when using electric motors instead of hand adjustment, the following arrangement is used. On the axis of the toothed wheel by means of which the adjustment is obtained (and which we shall call the adjusting pinion) there are two loose wheels, one of which can be operated by the handwheel and the other by means of the electric motor. The adjusting pinion can be connected with the wheel corresponding to the former or latter types of drive, by means of a friction coupling. This is operated by a milled head which

must be turned to the right or to the left till it reaches a stop. In the mid position the adjusting pinion remains uncoupled and the searchlight body can be adjusted freely by hand. By turning the milled head to the right the handwheel is thrown

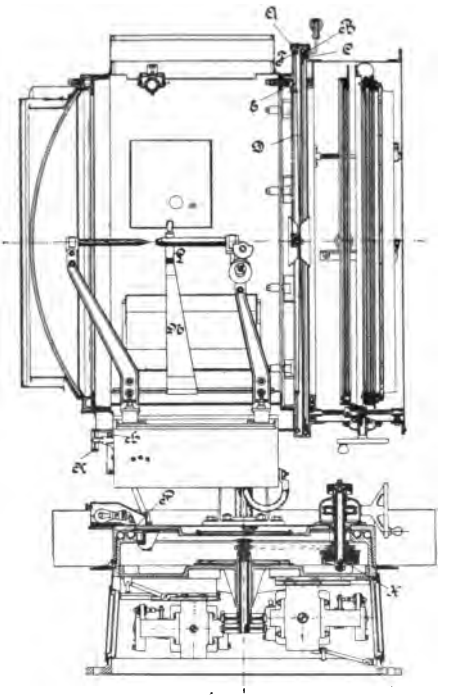


FIG. 24A.

into gear, by turning it to the left the motor drive is connected.

The motors, one for the turning and one for the tipping motion, are arranged either on the top of the turn-table, in which case an enclosed motor is used, or in the inside of the searchlight base. Since the

motors are protected when in the latter position motors of open type can then be used.

The latter arrangement is shown in Figs. 24A and 24B. Each of the motors drives a worm wheel by means of a worm. The two worm wheels are

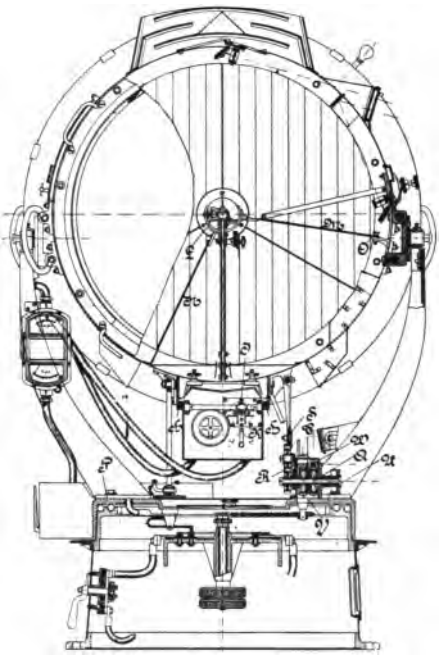


FIG. 24B.

arranged one above the other, and the spindle of one is carried through the centre of the other so that the axis of rotation of both coincides with the axis of the table. At their upper ends the spindles carry chain wheels, in which chains gear for transmitting the motion to the adjusting pinions.

The requirements which have to be fulfilled by

the turning and tipping motions of the searchlight are by no means the same, and the connections of the two motors are different in the two cases.

For the tipping motion a small angle only is required, since the direction of the object observed

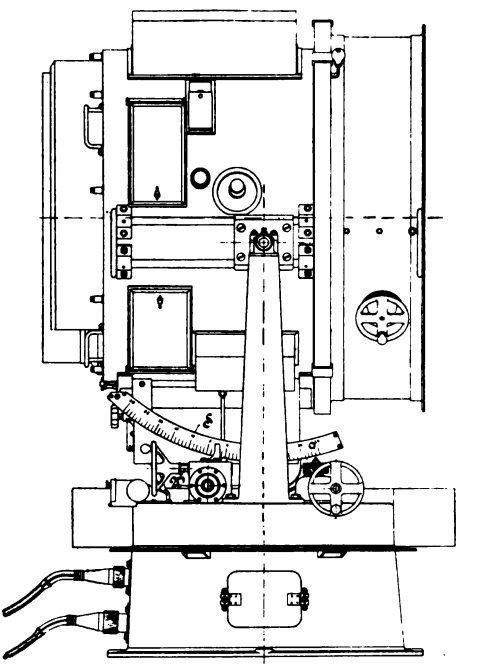


FIG. 24c.

is not usually very far from the horizontal. For the tipping motion a simple shunt motor is therefore used, which is arranged for both forward and backward movement, but whose speed is not adjustable. If the beam of light has to be raised or lowered more slowly than corresponds to the normal speed

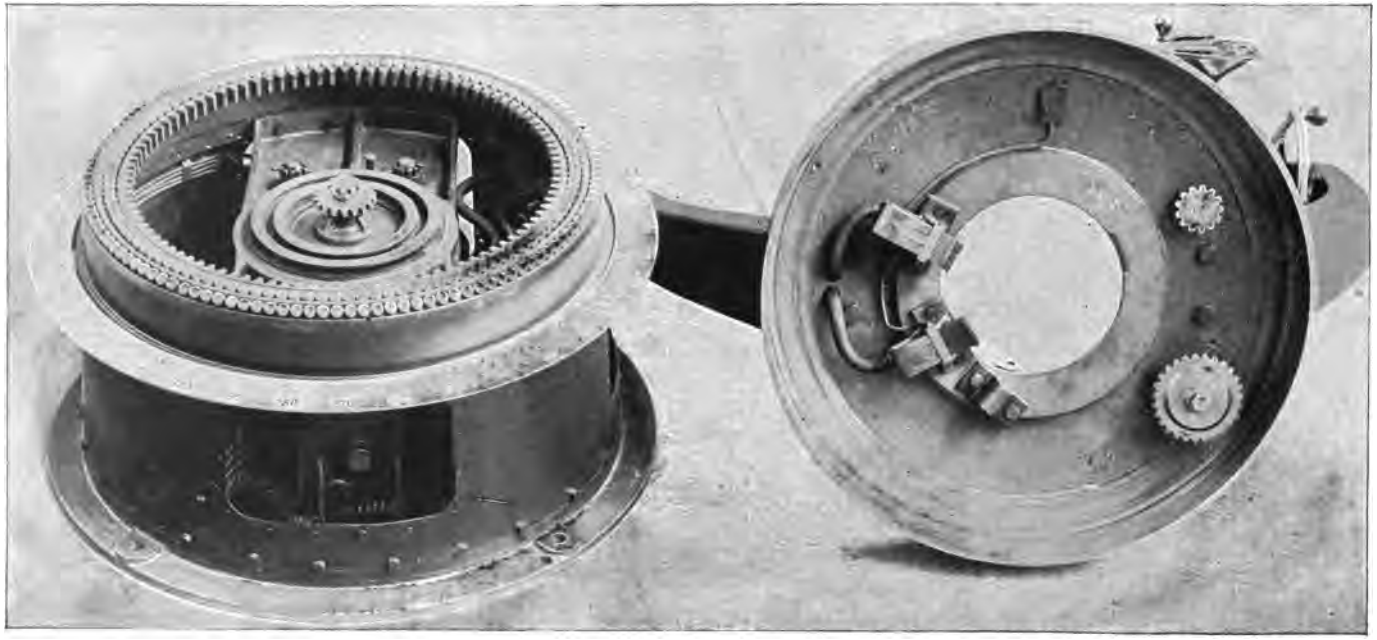


FIG. 25.

the motor is switched quickly in and out so as to reach the desired position in small steps.

Much severer conditions are required of the turning motor for the motion in the horizontal plane. The observer will require that the searchlight can be moved extremely slowly for examining the horizon, and also that it can be turned very quickly from one direction to a very different one. In order to meet these conditions, the motor is so arranged that its speed can be varied in the ratio of 1 : 24. The slowest speed which is required is one complete revolution in six minutes, and the fastest, one in fifteen seconds. This great range of regulation of the motor is obtained in the following way. The magnetic field is excited from a source of constant voltage, but the armature can be supplied with a higher or lower voltage corresponding to the speed required. For this purpose an adjustable resistance is put in series with the armature and carries the main current. The connections for various speeds are shown in Fig. 26A. In position 0 the motor has no voltage applied to its terminals and is therefore stationary. In positions 0 to 6 the voltage applied to the armature is gradually increased, causing a corresponding increase in the speed of the motor. In positions 7 to 9 a further increase in speed is obtained by decreasing the voltage applied to the field winding.

In order to prevent shock to the toothed gearing when the searchlight is suddenly stopped during

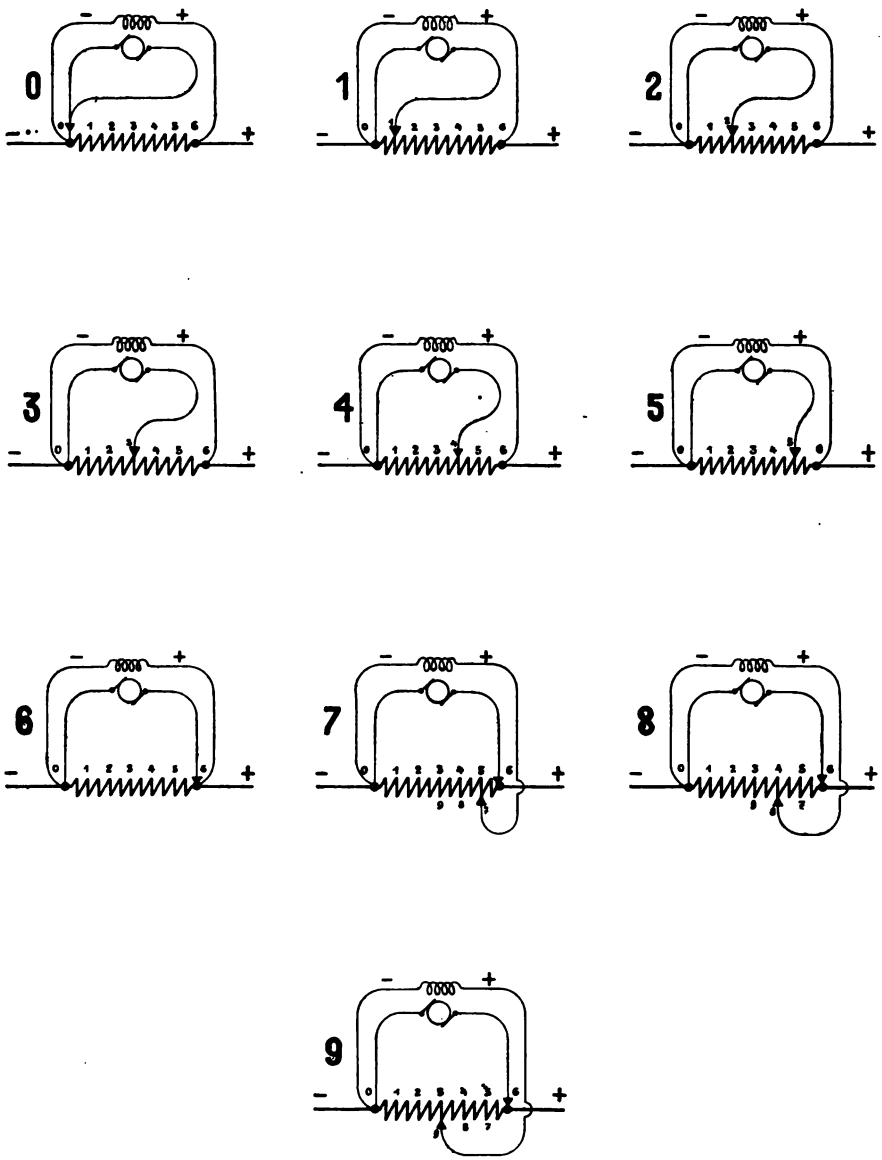


FIG. 26A.

its rapid motion, a flexible coupling is provided between the chain wheel and the spindle of the adjusting pinion. This takes up gradually in a distance of about 4° or 5° the energy stored in the moving mass, and brings the searchlight to rest without shock.

The connections for the motor, together with the accessory gear, are shown in Fig. 26B. The turning motor is there denoted by M_1, and the tipping motor by M_2.

In the intermediate position of the switch lever the motor armature is short-circuited through the following connections :—

The two terminals H_1 H_2 of the armature M_1 are put into connection with the contact rings IX and XI, as shown in the diagram, through the corresponding terminals H_1 H_2 of the throwover switch. The motor armature is then short-circuited by the slip ring brushes II, III which bridge the space between the two contact rings. This corresponds to the position marked o in the upper row of figures, Fig. 26B. If the starting lever is turned in a clockwise direction, say to position I, the pole H_1 of the armature is connected to step 5 of the resistance, while the other pole is connected to ring XII. The current then flows from step 5 of the resistance W over contact 5, brush II, ring X, terminal H_1 of the switch to the terminal H_1 of the searchlight through the armature M_1 to the terminal H_2 and back by ring XI through brush III to the other terminal. In other words, the motor

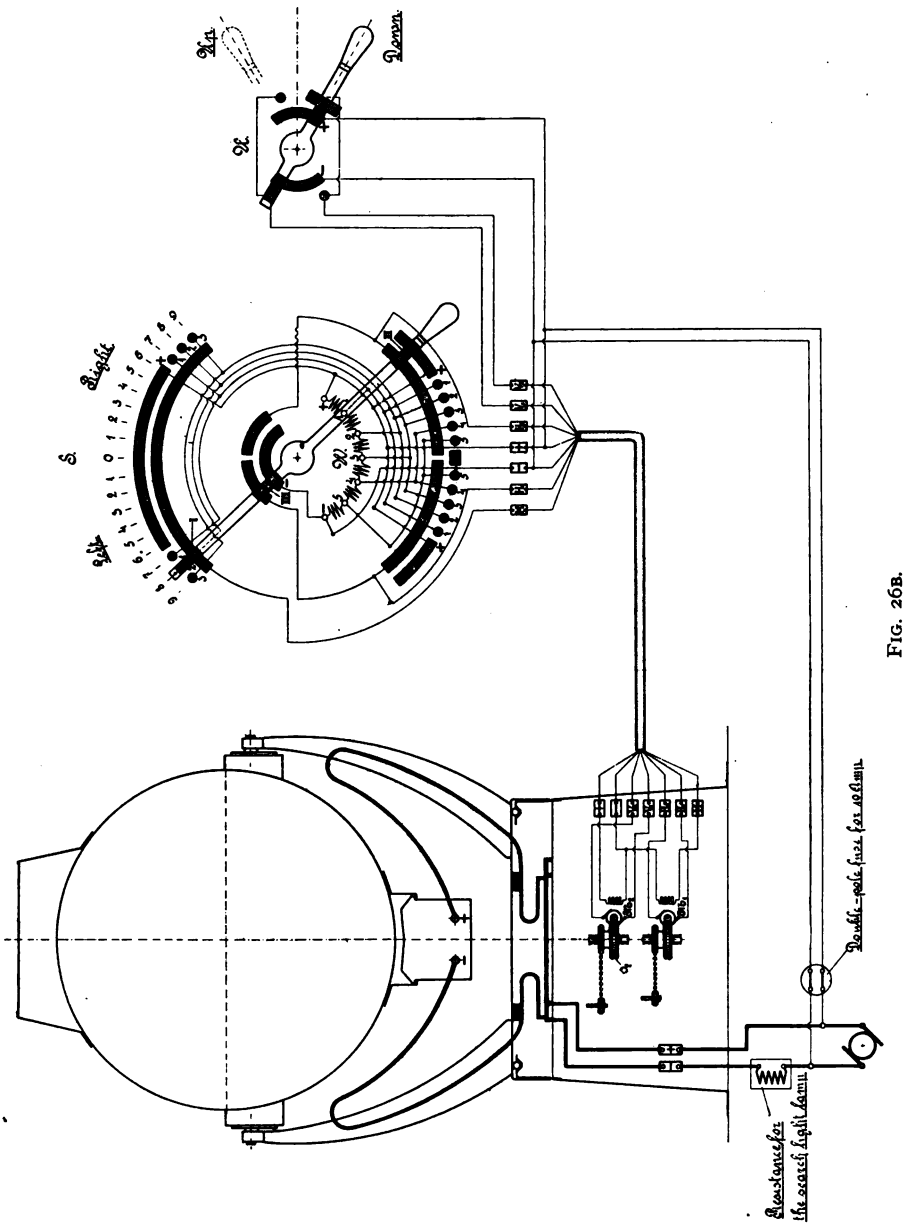

Resistances for the search light lamp
Double-pole fuse for 10 amp.

FIG. 26B.

armature M_1 has now the voltage applied to it which exists between one terminal of the resistance W and the contact 5, which is shown in Fig. 26B. This voltage is sufficiently large to start the motor M, but to keep it running at only a very slow speed. The beam will therefore move in a horizontal plane at its slowest speed. If the switch lever is now moved further to the contacts 4, 3, 2, 1, and finally to the last contact, the voltage applied to the armature is increased till finally in position 6 it reaches its full value. If the switch lever is now turned further to positions 7, 8 and 9 the voltage applied to the field of the motor is so far increased that the motor turns the searchlight at its maximum speed. The current for exciting the motor M_1 now flows when in position 8, say, from resistance step 2, from contact 2, to brush I, contact ring IV and the terminal M of the changeover switch to the terminal M of the searchlight and terminal M_1 of the motor to the negative terminal. The searchlight is brought to rest by turning back the switch lever to the mid position so that the motor armature is short-circuited, as already explained, and being driven forward by the kinetic energy of the moving searchlight, it runs as a dynamo, the current of which acts as a brake, so that the armature and the searchlight are almost instantaneously brought to rest. If the lever of the switch S is turned in the opposite direction the armature of the motor M_1 is reversed,

and the stages described above are gone through in the same order.

The motor M_2 for the tipping motion or motion in a vertical plane can be actuated in both directions by means of the double-pole throwover switch U. The course of the current can easily be followed from the diagram of connections, Fig. 26B. The switch S and the throwover switch U are mounted under the same cover, as shown in Fig. 28. The current is led to them by means of a double cable. It is not advisable to take the current for the motors direct from the searchlight lamp if it is ever necessary to operate the apparatus when the lamp is not burning, or if a lead is used which would cause a large drop in voltage when the lamp is burning. The voltage for the motors would in this case be different when the lamp is burning from when it is cut out. If the voltage drop in the lead, on the other hand, is small, and the steadying resistance is placed in the neighbourhood of the searchlight, the current for the motors can be taken off on the other side of the resistance. Since the throwover switch in any case must be erected at some distance from the searchlight, it will usually occur that the throwover switch can be connected direct to the source of supply by means of a double cable.

An 8-core cable leads from the controller to the searchlight base, one of the eight wires serving as a reserve.

If circumstances require that the speed of the

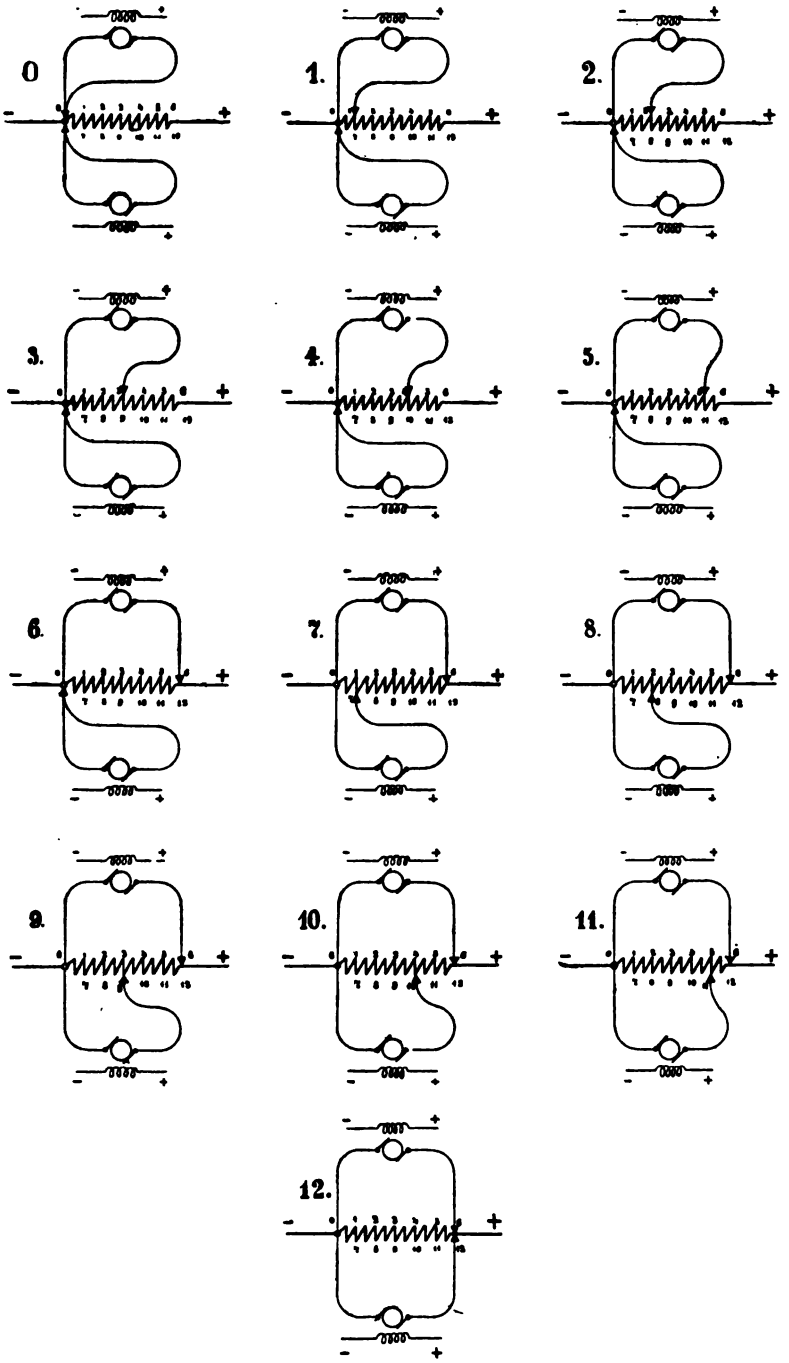


FIG. 27A.

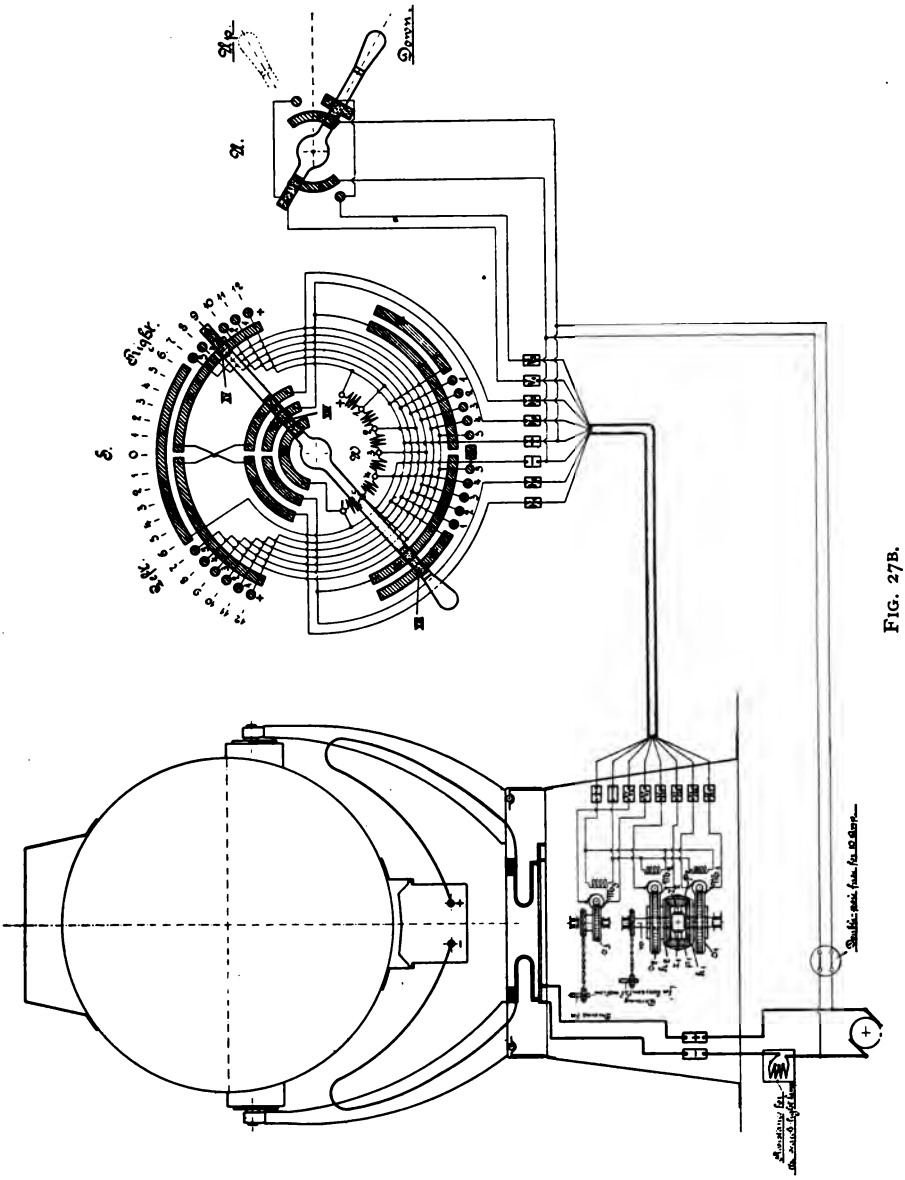


FIG. 27B.

searchlight is to be regulated over a still wider range, this can be secured by means of a second motor. The range of speed can then be increased to about double its previous value by letting both motors work through differential gearing on to the chain wheel of the turning motion.

The connection of the motors is similar to that described above, and is shown in Figs. 27A and 27B. A permanent resistance in series with the main current is used here also.

First of all one of the motors is connected to the first step of the resistance, and the voltage applied to it is gradually increased. The other motor, meanwhile, is at rest. When the first motor has reached its highest speed the second motor is connected in a similar manner to the first step of the resistance, the direction of rotation being the same as for the first motion. The voltage is then increased on the second motor until the full value is reached. The resulting speed will be the sum of the speeds of each motor, and the total range of speed will be doubled. Fig. 28 shows the switch as used for the method of connection above described.

The two motions for turning and tipping can also be obtained by means of a switch with only one lever, and as shown in Fig. 29.

Signalling by means of Searchlights.

Searchlights are not only useful for illuminating, but also for signalling to advanced positions or for

transmitting orders to distant sections of an army or to ships. For this purpose a searchlight must be fitted with a special signalling shutter, which allows the light to be reduced as required. Semi-

FIG. 28.

circular doors, which can be opened or closed by means of operating gear fitted to the side of the searchlight, and also shutters similar to a Venetian blind have shown themselves suitable. Curtains placed behind the front glass inside the casing, and which can be drawn aside, have been used;

also movable doors, consisting of iron plates, with small openings which are easily opened and closed, have been employed. All these arrangements have, however, shown certain defects. The last men-

FIG. 29.

tioned device can make use of only a small portion of the light, and is not always ready for use, as it has to be specially arranged in front of the glass. Semicircular doors have the disadvantage that they require a great deal of space when open, and in windy weather can be moved only with difficulty;

for constant use in signalling they are hardly suitable. Venetian blind shutters have been found suitable in many cases, but they also cut off part of the light even when open, and therefore reduce the effectiveness of the searchlight. Curtains are not durable, as up to the present no material is available which is sufficiently soft and can withstand the action of the light and heat for any length of time. All these arrangements suffer from the defect also that they do not completely cut off the light. The smallest openings still allow sufficient light to pass to make the position of the searchlight visible for a considerable distance.

The "Iris" Shutter.

The latest types of searchlight made by the Siemens-Schuckert Company are fitted with an arrangement which is far superior to any of those mentioned above. This consists of an Iris diaphragm constructed on similar principles to those used with photographic lenses, and so arranged that when closed the diaphragm fits into a circular groove in a central stop in the centre of the beam. This central stop (Figs. 30A and 30B) is suspended by steel rods or supported on cross pieces secured to the body of the searchlight. The "Iris" diaphragm consists essentially of a number of thin metal strips of a particular form, which at one end DD are connected to a ring fastened to the searchlight body by means of links E E at the points F F. The other ends are furnished each with a pivot working in a ring B

which slides in ball bearings in the first mentioned ring. The movable ring is fitted with a handle which projects through a slit in the casing. At the ends of the slit an India-rubber stop is provided which prevents shock when the lever is smartly brought to one end. The upper part of Fig. 30B shows the "Iris" diaphragm completely closed, half open and fully open. The lower half of the figure

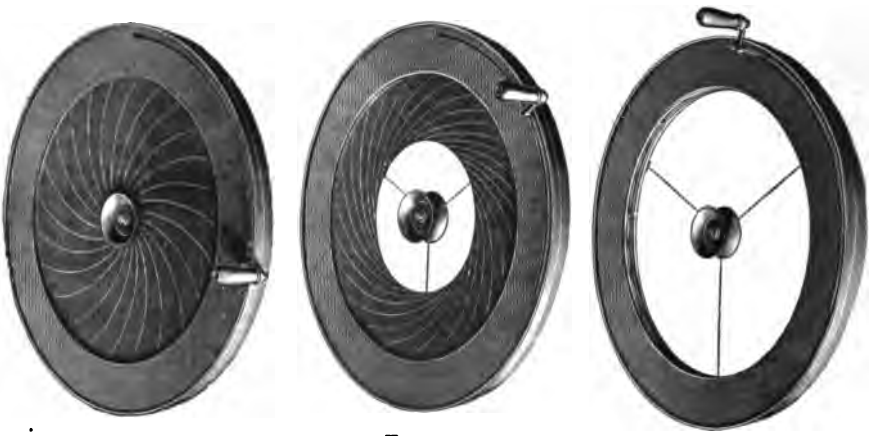
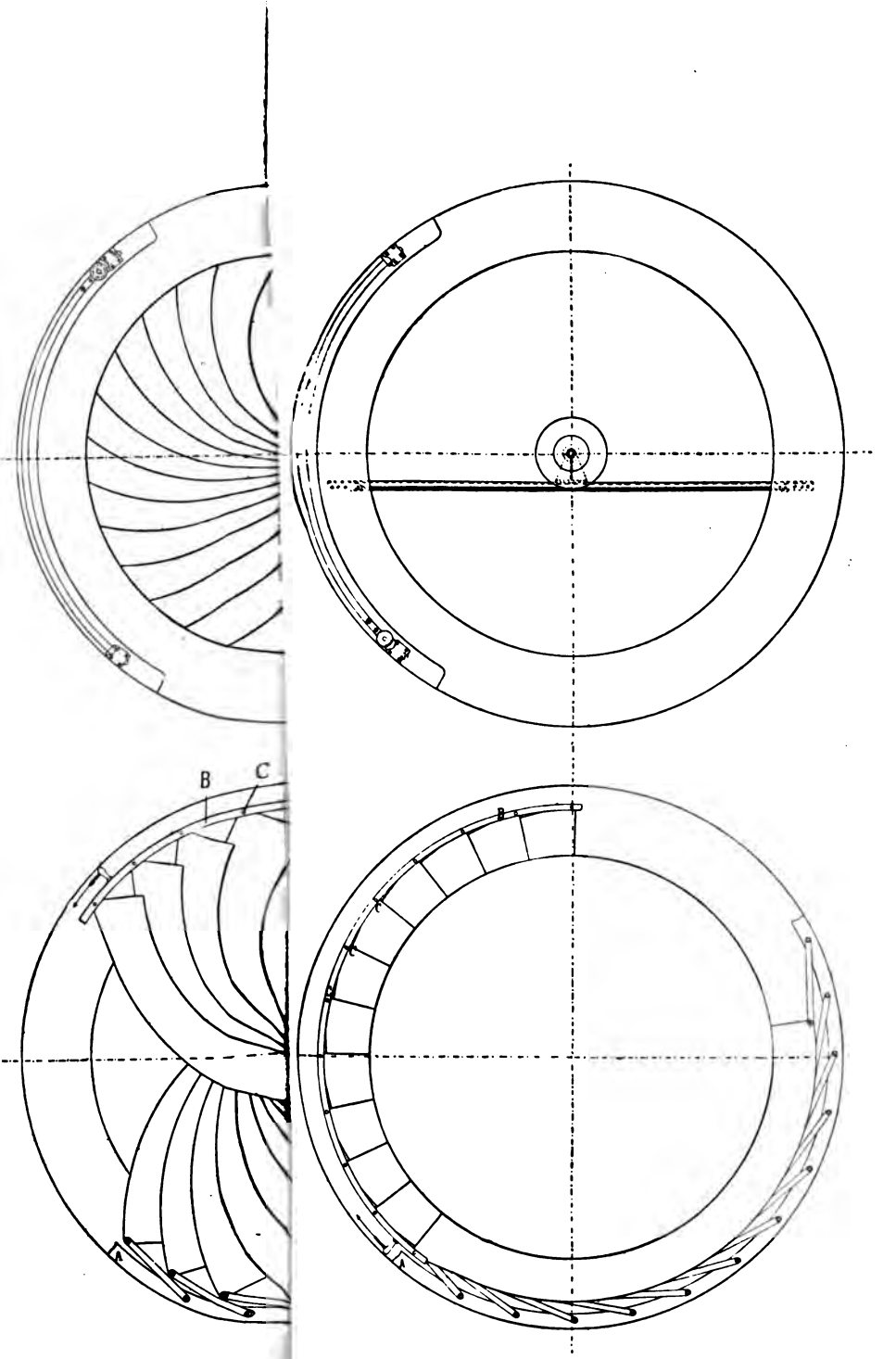


FIG. 30A.

shows the diaphragm in similar positions but with only about half the number of blades in position. When the diaphragm is fully open the blades lie side by side in a ring-shaped groove in the body of the searchlight. If the movable ring is turned towards the "closed" position the leaves are brought out of the groove and reduce the opening more and more until finally they fit into the groove of the central stop and completely close the front opening. The leaves are made wide enough to overlap one another with a sufficient margin, and



[*To face p.* 100.

when it is remembered that the free ends of the leaves are each covered by the fixed ends of the leaves lying over them, it will be seen that by this arrangement the light can be completely cut off. As a matter of fact searchlights which are fitted with "Iris" diaphragms do not show the slightest leakage of light even to a person standing in the immediate neighbourhood. This is of extreme importance for battleships, whose position it is desired to conceal from the enemy, but which must always have their searchlights ready for use in case of torpedo boat attacks.

The Disperser.

Perhaps the most important property of a searchlight is that of being able to send a closed concentrated beam of light in any desired direction with the smallest amount of dispersion in order to illuminate an object situated at a great distance, but we have also mentioned various cases in which it is desirable and even absolutely necessary to produce an illumination which is spread out in a broad beam in a horizontal direction. For this purpose optical glasses are used, which we have already mentioned at various times under the name of dispersers, and have partly explained.

If parallel rays of light fall on an ordinary convex or concave lens which is bounded by spherical surfaces these rays will be refracted and transmitted as if they came from the focus of the lens, that is, in the form of a cone of light whose apex is the

focus. If, however, the lens instead of being bounded by spherical surfaces is bounded by a cylindrical surface we get a so-called cylindrical lens (Fig. 31). Parallel rays falling on this lens have their direction unaltered in the plane parallel

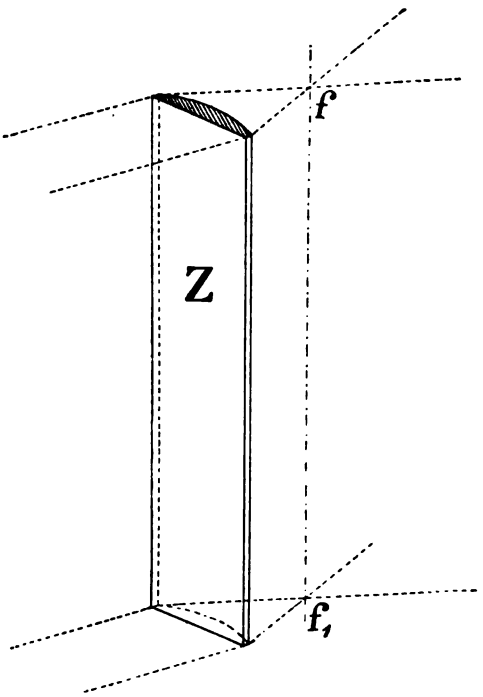


FIG. 31.

to the axis of the lens, but in the other plane are refracted in a similar way to the case of the spherical lens. The cylindrical lens therefore, instead of having a focal point has a focal line, and parallel rays are transmitted in the form of a wedge of light whose edge is in the focal line. If we arrange a number of such glasses so as to form a circular disc

of the same diameter as the front glass of the search-light, and with the strips parallel to one another and in a vertical plane, we obtain a series of wedges of light, which in a vertical plane have an angle of dispersion which is determined by the extent of the crater, as already described for a plain front glass. In the horizontal direction, on the other hand, these wedges of light pass out each with

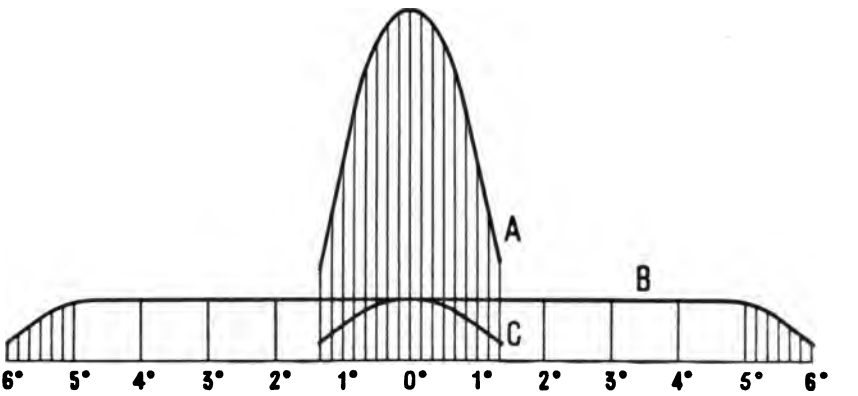


FIG. 32.

the same deviation and overlap one another in such a way that within the angle of dispersion the distribution of light is quite uniform, and outside that angle the beam of light rapidly falls off in intensity just as in the case of the concentrated beam. Fig. 32 shows the distribution of light, the abscissæ denoting the dispersion in degrees, and the ordinates the intensity of the illumination produced. Curve A gives the curve for a concentrated beam. Curve B shows it for a horizontal section, and curve C for a vertical section through the axis, both the

latter curves being for light dispersed at an angle of 12°.

As we have already seen, however, the simple disperser does not fulfil all requirements for use on a battleship, and for this reason the double disperser is often used.

The Double Disperser.

Figs. 33A and 33B show the arrangement used in an earlier type of searchlight, fitted with remote control and with the motors mounted on the rotating base. In place of the plain front glass or the single disperser two dispersers are fitted, with their glasses parallel and optically in line. By means of a parallel motion the distance between the two dispersers can be altered so that they may be quite close together or separated to a distance equal to the sum of the focal lengths of the glasses. In the searchlight shown in Figs. 33A and 33B the front disperser is carried on two rollers running on rails (34) fixed to the searchlight body, and is connected with them by eight enclosed double springs (35). It can be therefore considered as fixed, the springs being added only to prevent excessive vibration when guns are fired in the immediate neighbourhood, the use of double springs having shown itself very suitable for obtaining steadiness. The back disperser has a parallel motion on the one hand by means of two rollers working on the guides (34), and on the other hand by means of bolts (38) which are prolonged backwards and

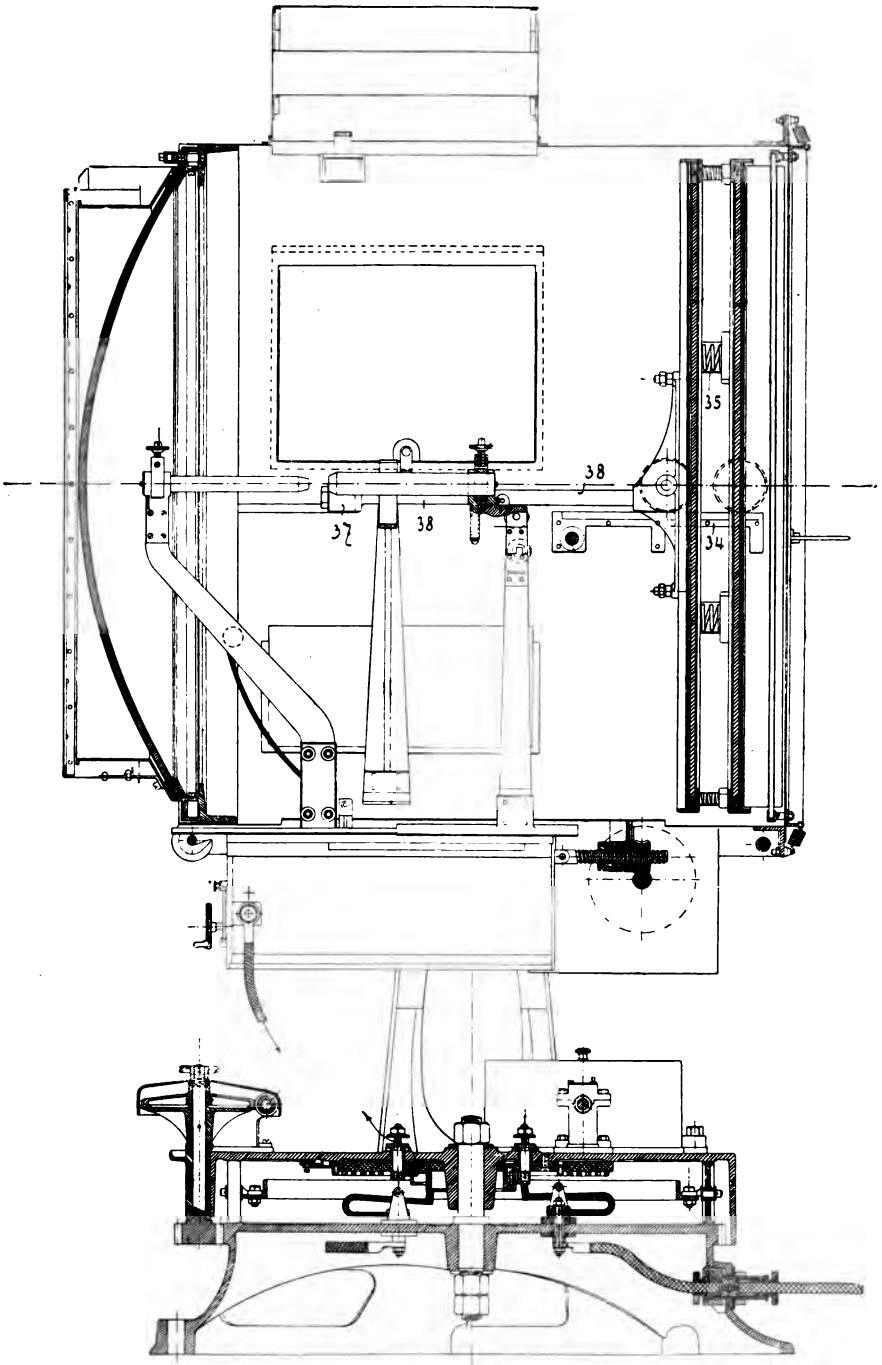


FIG. 33A.

connected with the frame of the disperser, and are fitted with eyes which project outwards through a slit in the casing. A thin spindle passes across the frame, to each end of which a small chain wheel is fitted outside the casing, and at one side a hand-wheel (42) also is provided. The chains are furnished with tighteners. The eyes projecting out of the casing, which we have mentioned above, gear with the upper part of the chains and are therefore moved forwards or backwards as the handwheel is turned and thus cause a corresponding motion in the back disperser. In order to keep the centre of gravity in a constant position lead weights are carried on the lower parts of the chains and therefore move in a direction opposite to that of the disperser.

If the back disperser is moved so that the distance between the two is equal to the sum of their focal lengths, rays reflected from the parabolic mirror are so refracted that they come together in the focal line F of the lenses (Fig. 34). These lines F are also the focal lines of the second system of lenses. The rays which diverge from these points will therefore be refracted through the front lenses so that they emerge parallel.

The front lenses have a smaller focal length than the back ones so that they are not illuminated over their whole width by the diverging beams. There is therefore a dark space between the parallel rays which are transmitted by the front glass, and a Venetian blind flashing shutter can therefore be

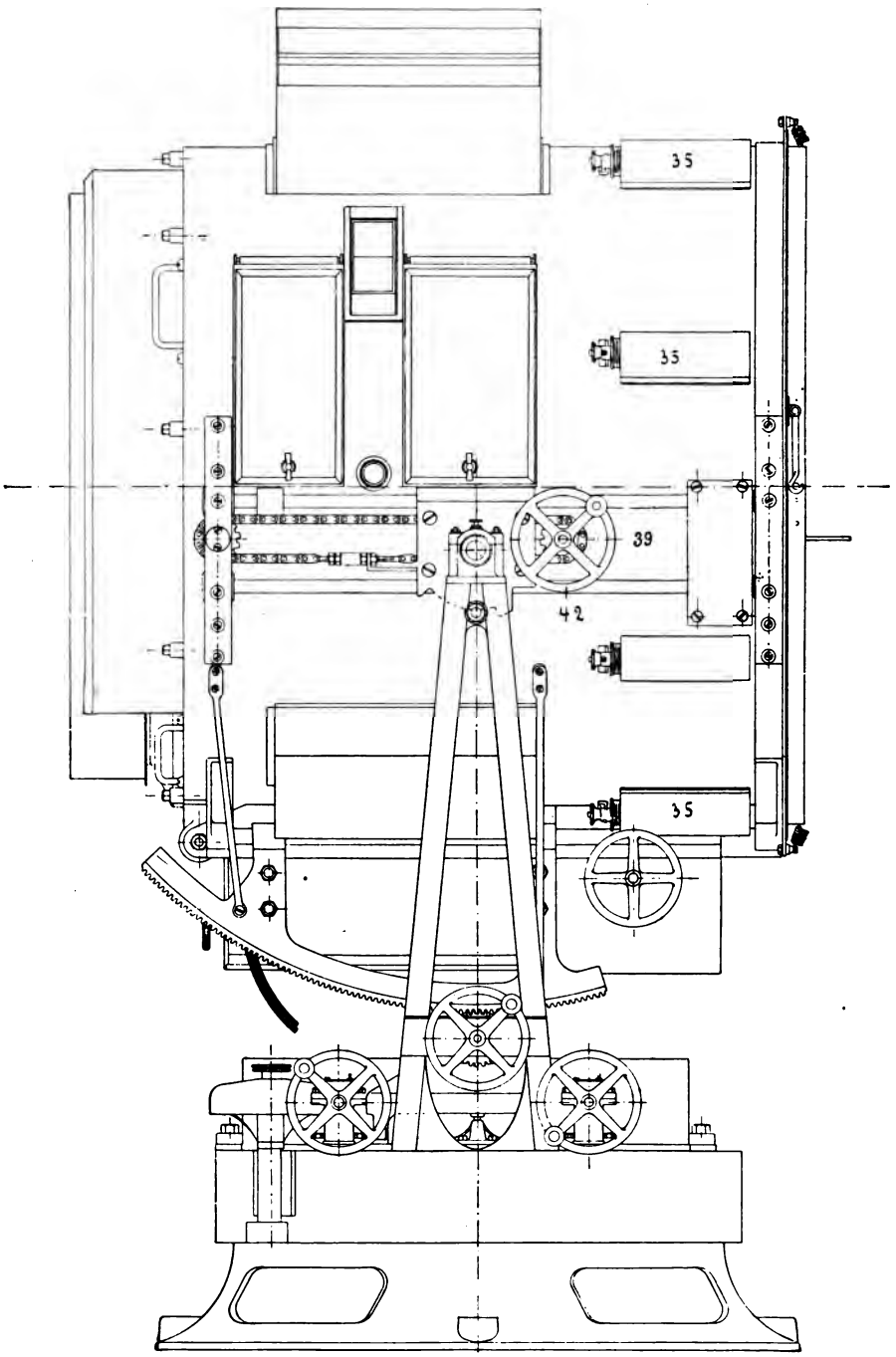


FIG 33B.

fitted with the individual bars in these dark spaces, so that no light is lost.

If the two dispersers are arranged with the smallest distance between them rays which come in a parallel beam from the parabolic mirror pass through the back lenses and the lenses of the front disperser, so that they are made still more

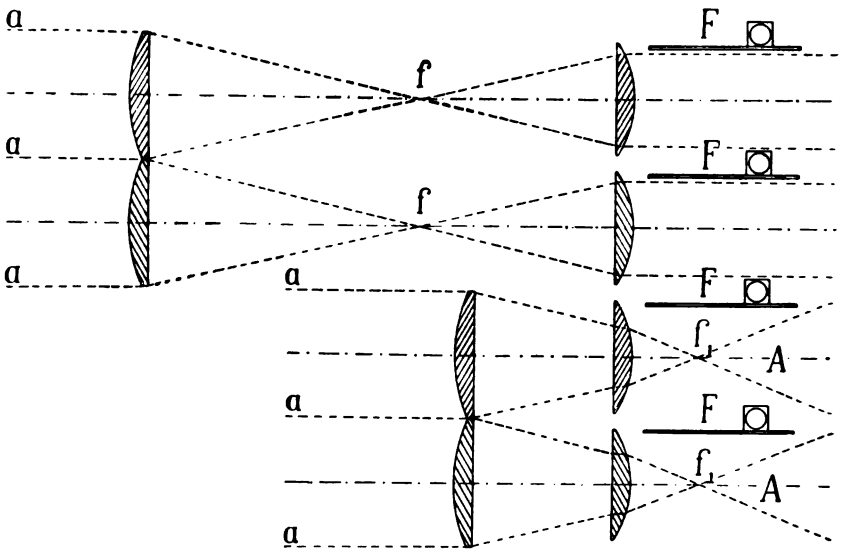


FIG. 34.

convergent, and the two lens systems therefore act as a single lens of smaller focal length. Since the rays of light are transmitted by the front lens in a convergent beam they will cross one another at the focal lines f^1 and from this point diverge at an angle A, and there therefore remains in this position also, a dark space for the bars F of the signalling apparatus.

Figs. 24A, 24B and 24C show a more recent type of searchlight fitted with dispersers. The sub-base has ball bearings, as the motors for remote control are arranged in this sub-base and protected by a water-tight cover. A double disperser is arranged in a special frame independent of the searchlight body, and can therefore be fixed as a whole in front of the searchlight, and taken down as required to be replaced by a plain front glass.

To obtain parallel motion of the disperser the following arrangement is used. At three equi-distant points on the disperser frame are placed right- and left-handed screws which screw into the two halves of the disperser respectively, so that when the screws are turned the disperser glasses are separated or brought closer together. The screws each carry a pinion, and all three pinions gear with a circular rack running in a ball-bearing extending round the whole circumference; all three screws must therefore turn together and the two disperser glasses are thus kept parallel and their centre of gravity remains constantly in the same position. One of the screws carries a conical pinion which gears with a second conical pinion fixed to a spindle passing through the casing. The outer end of this spindle carries a handwheel. If the handwheel is turned one screw is operated through the conical gearing, and the motion is transmitted by means of the circular rack to the other two screws, so that the motion is exactly the same at all three points and the two dispersers are uniformly racked

together or apart. The "Iris" diaphragm which is used to cut off the light is in this case arranged

FIG. 35.

between the searchlight and the double disperser. As the "Iris" diaphragm is not well suited for rapid

signalling a Venetian blind flashing shutter is also provided, and this is fitted to the front disperser and moves with it.

If it is required occasionally to use a plain front

FIG. 36.

glass instead of the double disperser, the former should be carried in a frame of considerable weight so that the balance of the whole searchlight may not be disturbed.

In the following pages several types of search-light made by the Siemens-Schuckert Company for military and naval use are illustrated.

Fig. 35 shows a specially light searchlight with automatic lamp and a 35 c.m. mirror, erected on a tripod-stand.

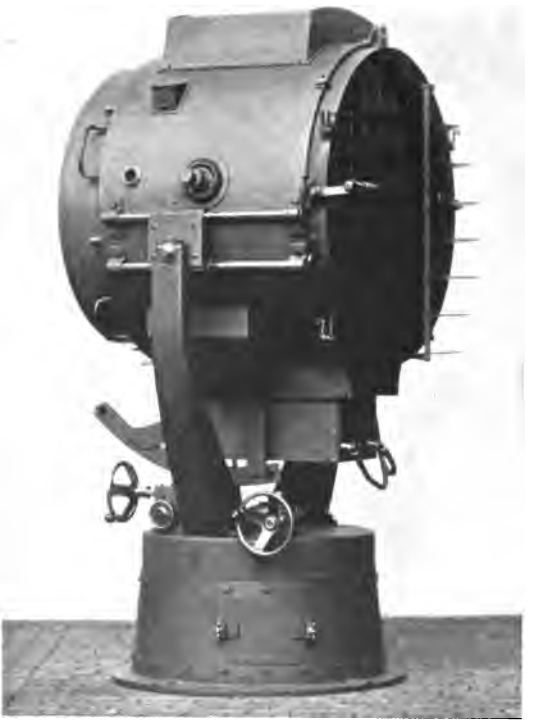


FIG. 37.

Fig. 36 shows an apparatus of the same type with a light-tight "Iris" shutter and a Venetian blind signalling shutter as used for torpedo boats.

Fig. 37 shows a simple model of medium size with a mirror diameter of 75 c.m. and a flashing shutter.

Fig. 38 shows a similar apparatus with a 90 c.m. mirror diameter and an "Iris" shutter.

Fig. 39 shows a searchlight having a mirror

FIG. 38.

200 c.m. in diameter, which is the largest which has yet been made.

Searchlights for Merchant Service and General Illumination.

We have so far described only those types of searchlight which are used for military or naval

purposes, but we should also mention for the sake of completeness that the merchant service makes use of small searchlights when passing narrow

FIG. 39.

waterways, principally in the Suez Canal. These serve to illuminate the banks and the water.

The searchlights as used on the Suez Canal are fitted with dispersers which spread out the light in such a way that there is a dark zone in the centre

embracing 5° with illuminated zones of 5° on each side. By a simple arrangement this disperser can be quickly changed for a second one mechanically coupled to the first, and which illuminates the waterway over an angle of 20°.

FIG. 40.

The searchlight itself is erected in front of the bow of the ship in a special housing.

Such a searchlight is illustrated in Fig. 40.

Dredgers, ice breakers and Customs' boats can also with advantage make use of searchlights in

their night duties, and a searchlight suitable for this purpose is illustrated in Fig. 41.

Also the various photographic processes make use of the property searchlights have of uniformly

FIG. 41.

illuminating surfaces of any desired extent, and of using the light available to the greatest advantage. A disperser is fitted in front of the searchlight, with its glasses arranged vertically so that the light is spread out horizontally at an angle of

usually 20°. Directly in front of this glass is placed a second disperser with its lenses arranged horizontally and which give the same dispersion as

FIG. 42.

the others but in a vertical direction. Since the separate glasses refract the light at a given angle so that the light from all the glasses overlap one another, it is possible to produce a perfectly uniform

illumination over a given area, and the size of this area can be arranged as desired by the choice of a suitable degree of dispersion. In most cases a distance from the screen of five metres is sufficient, and a uniformly illuminated area 1·8 metres in diameter can then be obtained.

The brightness of illumination at a distance of five metres when using a searchlight of 60 c.m. diameter, a lamp taking 60 amperes and a dispersion of 20°, such as we have assumed above, is about one-third as great as direct sunlight. The arrangement described is chiefly useful for reproduction of oil paintings and also for other branches of photography used in reproduction.

CHAPTER VIII.

TRANSPORTABLE POWER SUPPLY FOR SEARCHLIGHTS.

THE first transportable power waggons for searchlights were made by the firm of Sautter, Lemonier & Co., Paris. A steam engine, boiler and dynamo with accessories were mounted on a single waggon. The steam engine was a 3-cylinder engine running at a speed of about 950 revolutions per minute, and was direct coupled to the dynamo. The high speed enabled a machine of very small weight to be used, which is of extreme importance for a transportable set. A water-tube boiler was used. If the power required is only small, power waggons of this type are very suitable, but for higher outputs they are too heavy.

In the year 1885 the firm of Schuckert commenced building power waggons. They used a tubular boiler and a 4-cylinder engine, and produced a power set which in the important matter of weight was a distinct advance on the French power waggon. From about the year 1890 up to the present there has been keen competition between various firms to produce the largest output with the smallest weight. Reduction in the weight of boiler and increase in the speed of the engine are the only means of obtaining this. The dynamo can be made to suit the steam engine in all cases.

Power Waggon with Steam Turbine.

A further improvement was effected by the use of the steam turbine, and a waggon with this arrangement is shown in Fig. 43. It has now been

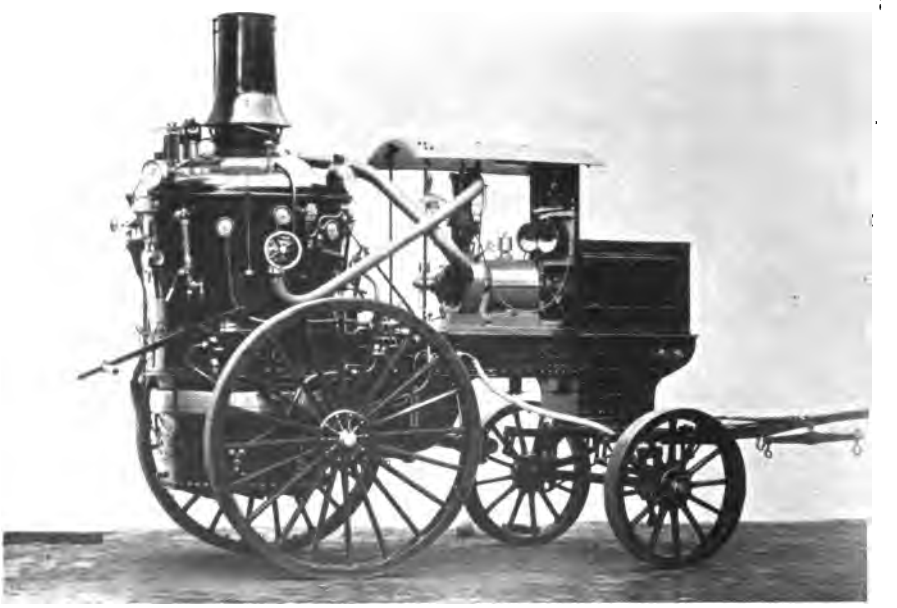


FIG. 43.

superseded by other constructions, but may be described shortly.

The body of the 4-wheeled waggon, which is constructed almost entirely of iron, is prolonged backwards to a ring-shaped support which carries the tubular boiler. In front of the boiler and projecting downwards, a water tank is arranged on the platform, to carry water for feeding the boiler.

Between the front and back wheels the steam engine is arranged, and in front of this and direct coupled to it is the dynamo, which is placed over the front wheels.

The boiler is suitable for a pressure of 175lbs. per square inch, and has the usual attachments.

The fuel is either anthracite coal or a mixture of anthracite coal and coke. In case of emergency even good burning wood can be used, but this requires great attention on the part of the stoker. As soon as the steam pressure exceeds 45lbs. per square inch, forced draught can be employed by using the boiler steam. The steam engine is a "Leval" turbine, which need not be further described.

The turbine shaft has a speed of 24,000 revolutions per minute, when the pressure is 135lbs. per square inch, and drives the dynamo shaft at a speed of 2,400 revolutions per minute through spur gearing. The dynamo is compound wound, and at a speed of 2,400 revolutions per minute has an output of 7·2 k.w.

The whole power waggon weighs about $3\frac{1}{3}$ tons, of which the principal part, about $2\frac{1}{2}$ tons, is on the back wheels.

It has already been mentioned that the steam engine has recently been superseded more and more by alcohol or petrol motors. We shall therefore describe several modern power waggons fitted with these motors as arranged by the Siemens-Schuckertwerke.

Power Waggon with Petrol or Alcohol Motor.

These power waggons are made, according to their output, either with four wheels as in Fig. 44, or with two wheels as in Fig. 45. The waggon is built in accordance with the usual practice for heavy military waggons, and has no further special features. With the exception of such parts as cannot be damaged by the weather or which must be arranged in the open in order to get sufficient cooling, the whole machine and apparatus is arranged with a covering. This consists of a sheet of iron housing with walls which can be partly removed. It affords the necessary protection from rain and dust.

The waggons are of similar build, whether they are to be used for petrol or alcohol motors, and have the same internal fittings, but the motors are different with regard to their cylinder dimensions and vaporisers. The alcohol motors are started with petrol, and if required can be run for some time with petrol if sufficient care is exercised. Besides the necessary supply of alcohol these waggons must therefore carry a small stock of petrol. The change from petrol to alcohol driving, and *vice versâ*, takes place by means of the cocks which are placed in the pipe between the vaporiser and the petrol and alcohol vessels.

With alcohol motors it is very essential that they should be run for some time with petrol in order to get rid of every trace of alcohol or products of

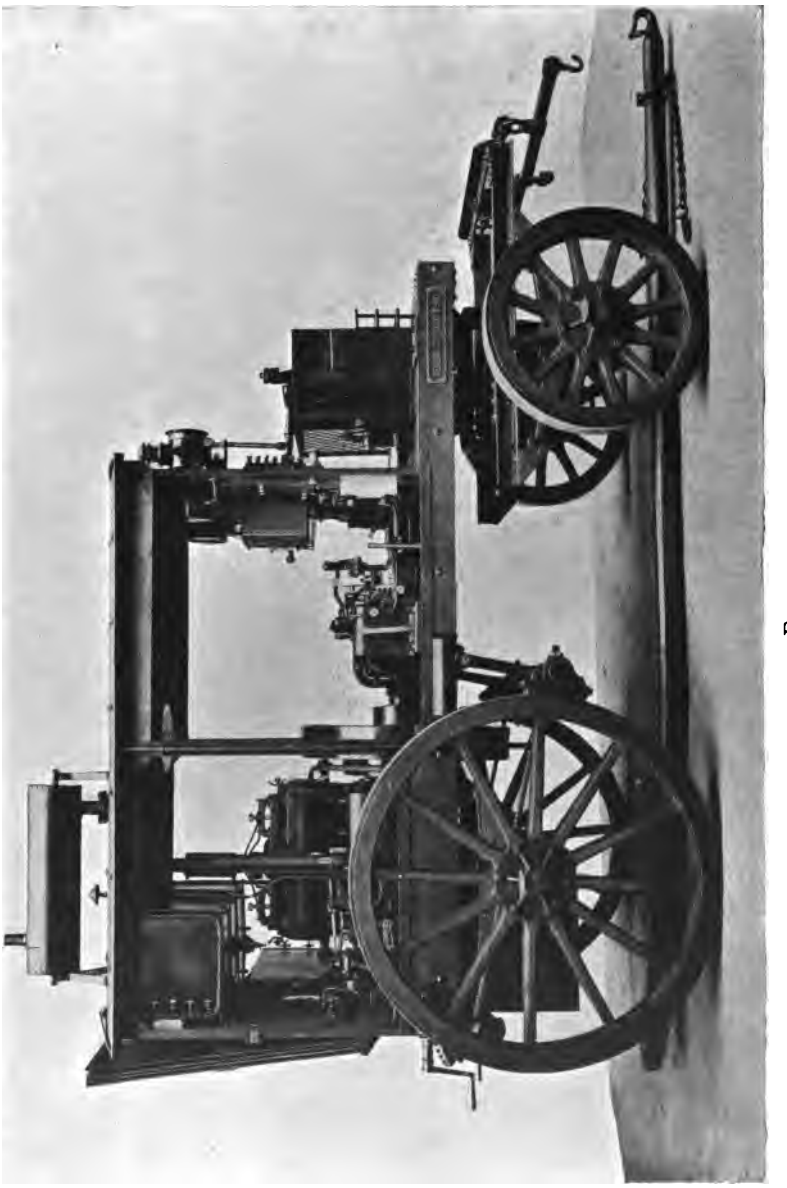


FIG. 44.

combustion of alcohol, as these are a serious cause of rusting.

The larger 4-wheeled wagon in Fig. 44 is of the following description :—

The rear part of the wagon contains a 4-cylinder, and in a few cases a 2-cylinder, motor, which is placed over the axle of the back wheel. The motor has the usual accessories, and is of the usual type.

The vaporiser is a so-called spray carburetter with float valve. In order to assist the vaporisation of the spirit, the vaporiser is heated by part of the hot exhaust gases. The usual form of magneto ignition with sparking plug is used.

The method of operation of the motor is as follows :—

As the piston passes backwards in the cylinder it draws fresh air through the vaporiser, together with petrol or alcohol vapour. On its forward stroke the charge is compressed and ignited shortly before the return stroke. This return stroke is then the one in which the work is done. On the second forward stroke the burnt gases are ejected, and the whole process is again repeated.

We see, therefore, that every four strokes—that is, every two revolutions—contains one working stroke, and that the motion during the other three strokes is carried on by means of the motor fly-wheel.

In order to get a more regular turning movement on the motor shaft, motors with two or four cylinders are used which have their working strokes arranged alternately.

Regulation of the speed is obtained by means of a centrifugal governor which operates a throttle valve and so influences the quantity of gas drawn in by the piston but does not alter its composition.

The cylinders of the motors are water cooled, the water being pumped through cooling vessels which surround the cylinders and the valves. The cooling water is thereby heated and is afterwards cooled off in a special vessel.

This cooling apparatus is placed at the forward end of the car, and consists of a vessel containing a large number of narrow tubes through which air is drawn by a ventilator. The total quantity of cooling water amounts to about 30 litres. The amount of cooling water used up is very small, owing to the small evaporation.

The burnt gases which are driven out into the exhaust pass out into a silencer, which is a large vessel arranged on the roof of the wagon and from which the gases pass outwards into the air. The principal petrol or alcohol vessel, which contains a number of small cocks to control the supply of liquid, is arranged on the roof of the waggon. The vessel for holding the lubricating oil, together with an oil pump, and in the case of alcohol motors the petrol holder also, are carried on the inside of the housing.

The electrical equipment of the waggon consists of a 4-pole dynamo with accessories and connections. The dynamo is connected to the motor shaft through a flexible coupling, and at 800

FIG. 45.

revolutions per minute gives 90 amperes at 80 volts, that is, 7·2 k.w.

On the inside of the front wall of the waggon the electrical gear, such as voltmeter, ammeter, shunt regulating resistances for the dynamo, fuses and switches, are secured. The measuring instruments are suspended on springs in order to protect them from shock while travelling. To connect the searchlight leads two cable couplings of a special construction are used. To connect the other leads two terminal boards are provided at the front end of the wagon.

At the rear end of the car, and below the motor, a box for carrying tools and spare parts is provided.

The weight of the completely equipped waggon, with spirit and oil supply and full supply of cooling water, amounts to about 2·4 tons. The waggon is usually arranged for four horses, and the driver has a seat in front.

Fig. 45 shows a waggon for a smaller output of 4·2 k.w., which has only two wheels. In general principle this smaller waggon is the same as the larger one described above. The differences which exist are only in the size and arrangement of the separate parts. The motor has only two cylinders; and vaporiser, ignition apparatus and cooling arrangements are exactly the same as in the larger waggon. It should be remarked that in this waggon the upper part is not carried on coach springs but on indiarubber pads.

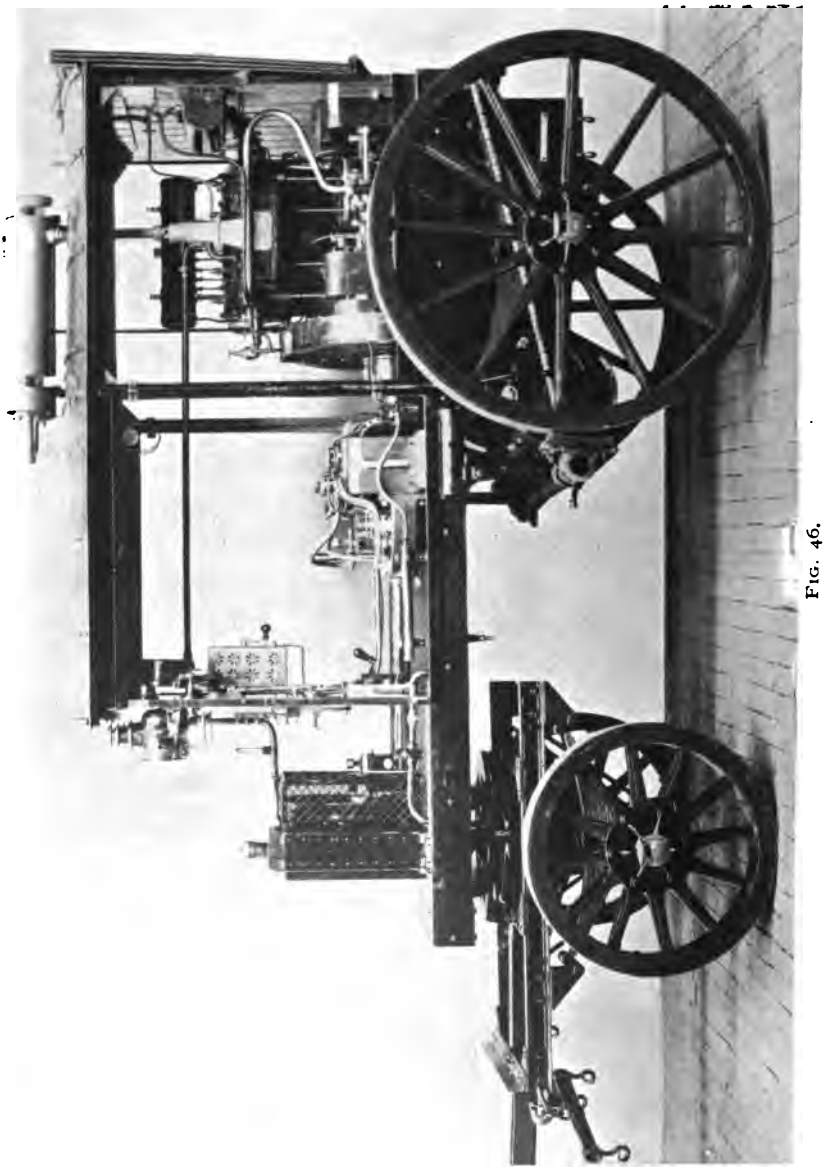


FIG. 46.

Power Waggon with Petroleum Motor.

In those cases in which alcohol or petrol may not be used on account of the difficulty in procuring them or the danger of fire, transportable sets with paraffin motors may be used.

Figs. 46 and 47 show two power waggons fitted with petroleum motors. In general build these waggons are similar to those with benzine or alcohol motors already described, but the motors show some differences in the type of the vaporiser, and in most cases also in the lubrication and the ignition. The ignition takes place by breaking the current produced by the inductor, at a point inside the cylinder by means of a lever operated from the outside. At the point where the current is broken an arc is formed which causes the ignition. Instead of this system the high tension ignition already described may be used, but care must be taken that the sparking plugs are kept quite clean.

With a petroleum motor the reservoir is preferably arranged below the wagon. In this way the paraffin is fed under somewhat reduced pressure which is an advantage, and it is also easier to fill the reservoir. The pressure in the reservoir is first produced by means of a small hand-driven air pump. As soon as the motor is up to speed the pressure is automatically kept up by sending part of the exhaust gases into the reservoir by means of a pressure reducing and regulating valve.

The speed of this motor is also regulated by

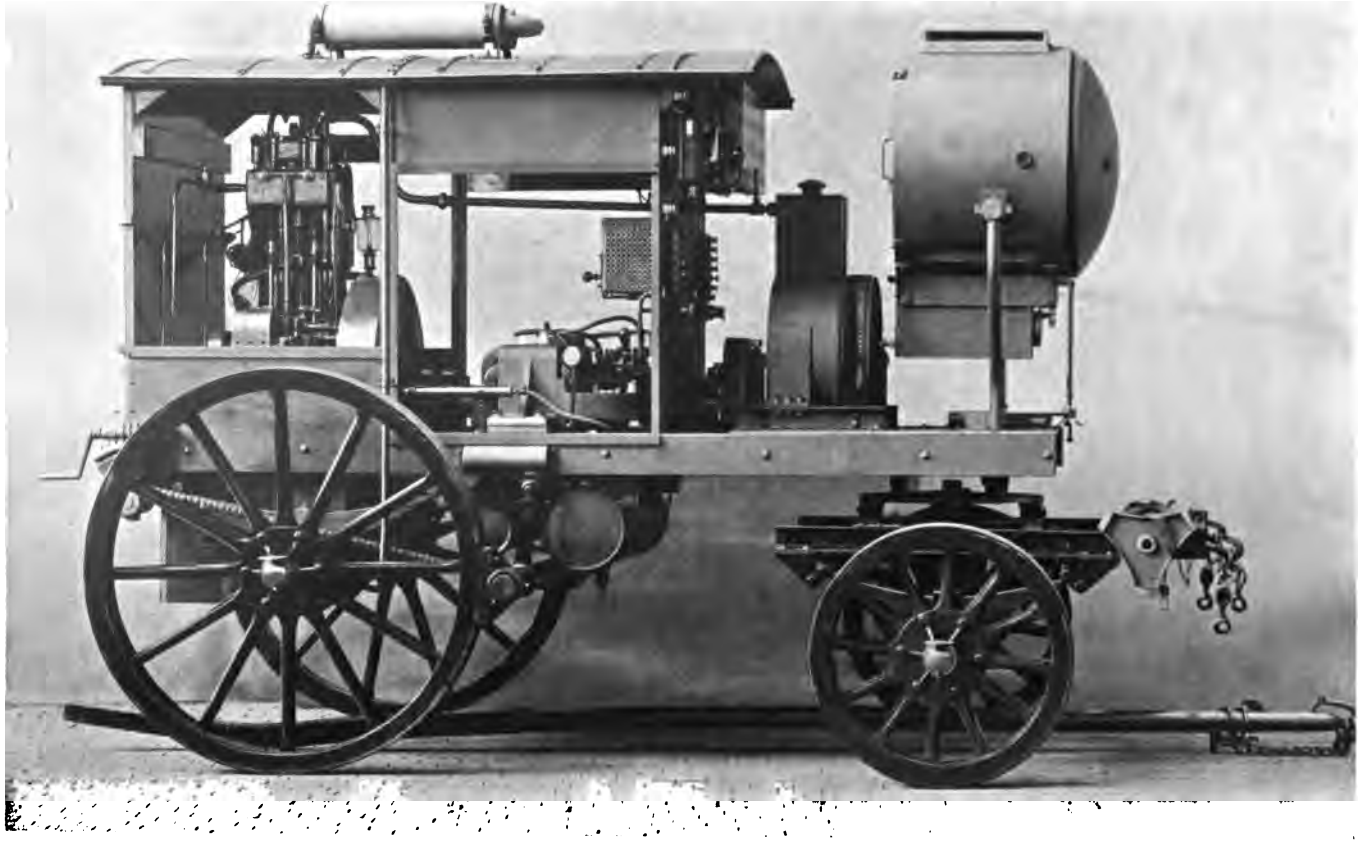


FIG. 47.

means of a centrifugal governor which regulates the quantity of the mixture drawn in by the motor.

The petroleum motor is started by means of petrol, just as in the case of the alcohol motor. As soon as the motor is sufficiently warm petroleum can be used. It is not necessary in this case to run for some time with petrol before shutting down.

The electrical equipment of a power waggon equipped with a petroleum motor is exactly the same as described above for that with the petrol or alcohol motor.

The dynamo of the waggon shown in Fig. 46 can produce 7·2 k.w., 90 amperes at 80 volts.

The completely equipped waggon has a weight of $2\frac{1}{2}$ tons.

The waggon in Fig. 47 has an output of 4·8 k.w., that is, 60 amperes at 80 volts. The waggon serves at the same time to carry the searchlight, and when in use the latter can be erected on a tripod stand.

The weight of the waggon complete is 2·3 tons.

APPENDIX.

PHYSICAL QUANTITIES USED IN PHOTOMETRY.

If a small screen of area f is placed perpendicular to the rays coming from a source of light of intensity J and at a distance r from it, the quantity of light falling on the screen will be :—

$$\Phi = \frac{Jf}{r^2}.$$

f/r^2 is a measure of the solid angle subtended at the source by the small area; the quantity of light given out in a small solid angle ω can therefore be expressed as

$$\Phi = J\,\omega.$$

If the intensity is the same in all directions the total quantity of light emitted by the source is

$$\Phi = \frac{4\pi r^2}{r^2} J$$

$$\text{or} \quad = \quad 4\pi J.$$

If the intensity is different in different directions, the average intensity for all directions is called the mean spherical intensity, and the average intensity for all horizontal directions is called the mean horizontal intensity.

The units employed in this book are the standard units used in Germany. The unit of intensity is called the Hefner (H.E.), and is equal to 0·91 English standard candle-power or c.p.

The unit quantity of light is called the Lumen (Lm.), and is the quantity emitted by one H.E. in unit solid angle.

The illumination E at any point is the ratio of the quantity

of light falling on a small area surrounding the point and placed normally to the rays, to the magnitude of that area, of

$$E = \frac{\phi}{f},$$

or since

$$\Phi = J\frac{f}{r^2},$$

we have

$$E = \frac{J}{r^2}.$$

The unit of illumination is the Lux (Lx.), and is the illumination produced by one H.E. at a distance of one metre.

The intrinsic brilliancy i of a source of light is the ratio of the average intensity J of a part of the surface to the area s of that part or

$$i = \frac{J}{s},$$

it is therefore expressed in H.E. per sq. cm.

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